

## **Effective Dose of Positioning Scans for Five CBCT Devices**

Stona R. Jackson

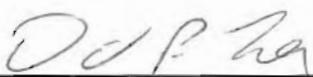
APPROVED:



Ryan L. Snyder, D.D.S., M.S., Supervising Professor



Brent J. Callegari, D.D.S., M.S.D., Program Director



David P. Lee, D.M.D., M.S., Chairman

1-1-2016

Date

APPROVED:



Drew W. Fallis, D.D.S., M.S., Dean, Air Force Postgraduate Dental School

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Stona Jackson, CPT, DC  
Tri-Service Orthodontic Residency Program  
Air Force Post Graduate Dental School  
Uniformed Services University  
25May2016



## Effective Dose of Positioning Scans for Five CBCT Devices

Stona R. Jackson

A thesis

presented to the faculty of the Orthodontic Graduate Program  
in partial fulfillment of the  
requirements for the degree of

Master of Science

Uniformed Services University of the Health Sciences  
Postgraduate Dental College

2016

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San Antonio, Texas

The views expressed in this study are those of the authors and do not reflect the official policy of the United States Air Force, the Department of Defense, or the United States Government. The authors do not have any financial interest in the companies whose materials are discussed in this article.

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---

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---

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I give thanks for Noah, Olivia, and Saskia, who gave me three reasons to work hard every day. Without their love and support, I would never have made it through dental school and residency.

## DEDICATION

This thesis is dedicated to my wife, Safia, who never gave up on me and encouraged me to try something new after falling out of love with chemistry.

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Stona R. Jackson, D.D.S., CPT, USA, DC  
Tri-Service Orthodontic Residency Program  
Air Force Post Graduate Dental School  
June 2016

Uniformed Services University of the Health Sciences  
Postgraduate Dental College

ABSTRACT

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**Objective:** While three-dimensional radiographs are commonly used in dentistry and prior work has focused on the effective dose of Cone Beam Computed Tomography (CBCT), little is known about the dose or frequency of use of the preliminary scans used to position patients prior to a full scan. **Methods:** Positioning scan effective dose was measured with metal–oxide–semiconductor field-effect transistor (MOSFET) dosimeters for five CBCT devices in a postgraduate dental clinic. Additionally, log files from 2013–2015 were examined to obtain information on the clinical use of preview scans for the two highest dose devices. **Results:** Highest effective doses were observed for the 3D Accuitomo 170 ( $8 \times 8 \text{ cm}^2$ , 45  $\mu\text{Sv}$ ). Further, an average of 3.3 and 1.3 previews were required to position patients for the i-CAT and Accuitomo devices, respectively. **Conclusion:** Positioning scans deliver a range of effective doses between <1  $\mu\text{Sv}$  and 45  $\mu\text{Sv}$  (equivalent to a panoramic radiograph), depending on the device and the field of view setting. These findings demonstrate the variability of dose across CBCT devices and emphasize the importance of careful and conservative use of preview scans in patient examinations.

## TABLE OF CONTENTS

Acknowledgements .....	iii
Dedication .....	iv
Copyright Statement .....	v
Abstract .....	vi
Table of Contents .....	vii
List of Tables .....	ix
List of Figures .....	xi
Chapter 1. Introduction .....	13
1.1 Rationale .....	13
1.2 Effective Dose: Sources and Definitions .....	13
1.3 Measuring Effective Dose .....	15
Chapter 2. Objectives .....	18
2.1 Study Aims .....	18
2.2 Study Hypotheses .....	18
2.3 Null Hypotheses .....	18
Chapter 3. Materials and Methods .....	19
3.1 Experimental Design .....	19
3.1.1 Dose Phantom .....	19
3.1.2 Dosimeters .....	19
3.1.3 CBCT Scanners .....	20
3.2 Device Log Files .....	21
3.2.1 i-CAT Log Files .....	21
3.2.2 Accuitomo Log Files .....	22
3.3 Figures of Materials and Methods .....	24
Chapter 4. Results .....	29

4.1 Preview and Full Scan Effective Dose.....	29
4.2 Effective Doses Compared to Standard Cephalometric and Panoramic Radiographs .....	30
4.2.1 Counting i-CAT Previews Per Full Scan .....	31
4.2.2 Counting Accuitomo Previews Per Full Scan.....	32
Chapter 5. Discussion .....	35
5.1 Effective Dose of CBCT Full Scans .....	35
5.2 Effective Dose of CBCT Preview Scans .....	37
5.2.1 i-CAT Previews Per Full CBCT Scan.....	38
5.2.2 Accuitomo Previews Per Full CBCT Scan .....	39
Chapter 6. Study Conclusions.....	42
Appendices .....	43
Literature Cited.....	77

## LIST OF TABLES

Table 1.1. ICRP 2007 recommended tissue weighting factors. ....	15
Table 1.2. Effective doses from imaging (from Bornstein 2014). ....	17
Table 3.1. Phantom slices, tissues, and sensor locations.....	20
Table 3.2. Devices and settings.....	21
Table 5.1. Effective doses (ED) from two runs using the Accuitomo device. ....	36
Table 5.2. Comparison of effective dose to individual tissues in Accuitomo previews, 50 exposures at each field of view. ....	38
Table 5.3. Previews per full scan for different devices and fields of view. ....	39
Table A.1. Accumoto full scan 8 x 8 cm <sup>2</sup> .....	43
Table A.2. Accumoto full scan 8 x 8 cm <sup>2</sup> .....	44
Table A.3. Accuitomo 50 preview scans 8 x 8 cm <sup>2</sup> . ....	45
Table A.4. Accuitomo 50 preview scans 8 x 8 cm <sup>2</sup> . ....	46
Table A.5. Accuitomo full scan 6 x 6 cm <sup>2</sup> .....	47
Table A.6. Accuitomo full scan 6 x 6 cm <sup>2</sup> .....	48
Table A.7. Accuitomo full scan 4 x 4 cm <sup>2</sup> .....	49
Table A.8. Accuitomo full scan 4 x 4 cm <sup>2</sup> . ....	50
Table A.9. Accuitomo 50 preview scans 4 x 4 cm <sup>2</sup> . ....	51
Table A.10. Accuitomo 50 preview scans 4 x 4 cm <sup>2</sup> . ....	52
Table A.11. Accuitomo 50 preview scans 4 x 4 cm <sup>2</sup> (repeat). ....	53
Table A.12. Accuitomo 50 preview scans 4 x 4 cm <sup>2</sup> (repeat). ....	54
Table A.13. Planmeca full scan 23 x 16 cm <sup>2</sup> .....	55
Table A.14. Planmeca full scan 23 x 16 cm <sup>2</sup> .....	56
Table A.15. Planmeca 50 preview scans 23 x 16 cm <sup>2</sup> . ....	57
Table A.16. Planmeca 50 preview scans 23 x 16 cm <sup>2</sup> . ....	58
Table A.17. Carestream full scan 17 x 13.5 cm <sup>2</sup> .....	59
Table A.18. Carestream full scan 17 x 13.5 cm <sup>2</sup> . ....	60
Table A.19. Carestream 50 preview scans 17 x 13.5 cm <sup>2</sup> . ....	61
Table A.20. Carestream 50 preview scans 17 x 13.5 cm <sup>2</sup> . ....	62
Table A.21. i-CAT full scan 23 x 17 cm <sup>2</sup> .....	63
Table A.22. i-CAT full scan 23 x 17 cm <sup>2</sup> .....	64

Table A.23. i-CAT 50 preview scans 23 x 17 cm <sup>2</sup> .....	65
Table A.24. i-CAT 50 previews 23 x 17 cm <sup>2</sup> .....	66
Table A.25. i-CAT FLX full scan 23 x 17 cm <sup>2</sup> .....	67
Table A.26. i-CAT FLX full scan 23 x 17 cm <sup>2</sup> .....	68
Table A.27. i-CAT FLX 50 previews 23 x 17 cm <sup>2</sup> .....	69
Table A.28. i-CAT FLX 50 previews 23 x 17 cm <sup>2</sup> .....	70
Table A.29. i-CAT background scan 23 x 17 cm <sup>2</sup> .....	71
Table A.30. i-CAT background scan 23 x 17 cm <sup>2</sup> .....	72
Table A.31. Planmeca 5 panoramic radiographs.....	73
Table A.32. Planmeca 5 panoramic radiographs.....	74
Table A.33. Planmeca 50 lateral cephalometric radiographs.....	75
Table A.34. Planmeca 50 lateral cephalometric radiographs.....	76

## LIST OF FIGURES

Figure 3.1. Example of log file text generated for two previews and a full scan for patient 1992 on 24 September 2014.....	22
Figure 3.2. Three full scans and six scout images taken for one patient between 0831 and 0856 on 20 March 2015. <i>Note:</i> Timestamp format: YYYYMMDDHHH.....	23
Figure 3.3. RANDO Phantom.....	24
Figure 3.4. i-CAT Next Generation imaging setup. ....	24
Figure 3.5. i-CAT Next Generation sample preview.....	25
Figure 3.6. Accuitomo 170 imaging setup. ....	25
Figure 3.7. Accuitomo 170 sample preview. ....	26
Figure 3.8. Carestream 9300 imaging setup.....	26
Figure 3.9. Carestream 9300 sample preview. ....	27
Figure 3.10. Planmeca Promax 3D imaging setup.....	27
Figure 3.11. Planmeca Promax 3D sample preview. ....	28
Figure 4.1. Full scan effective doses by device and field of view specification. ....	29
Figure 4.2. Preview scan effective doses by device and field of view specification. ....	30
Figure 4.3. Effective doses of Planmeca standard cephalometric and panoramic radiographs versus Accuitomo 8 x 8 cm <sup>2</sup> preview radiograph.....	30
Figure 4.4. Preview scan data and panoramic radiograph effective doses relative to a single standard cephalometric radiograph. <i>Note:</i> The effective doses displayed for the panoramic and Accumoto 8 x 8 cm <sup>2</sup> are not to scale. ....	31
Figure 4.5. Frequency counts for 1-7 previews per full 23 x 17 cm <sup>2</sup> i-CAT CBCT. ....	32
Figure 4.6. Frequency counts for 8+ previews per full 23 x 17 cm <sup>2</sup> i-CAT CBCT. ....	32
Figure 4.7. Example Accuitomo log data for patient #453980479 receiving 8 previews and a CBCT (either 6 x 6 cm <sup>2</sup> or 4 x 4 cm <sup>2</sup> ). ....	33
Figure 4.8. Frequency counts for 1-3 previews per full Accuitomo CBCT.....	33
Figure 4.9. Frequency counts for 4+ previews per full Accuitomo CBCT.....	34
Figure 4.10. Frequency counts for number of full Accuitomo CBCT scans per patient, all fields of view.....	34
Figure 5.1. Accuitomo 50 preview exposure runs repeated and compared to background measurement. ....	37

Figure 5.2. Collage of i-CAT images of a single patient who received two full scans and 26 previews over 17 minutes.....	39
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## Chapter 1. INTRODUCTION

### 1.1 RATIONALE

True three-dimensional imaging, in the form of Cone-Beam Computed Tomography (CBCT), is frequently used for diagnosis in dental and orthodontic treatment planning. This form of imaging results in increased radiation dose compared to conventional lateral cephalometric radiographs; as such, many exposures to this type of radiation may contribute to cancer in sensitive tissues included in the field of view (e.g., bone marrow, salivary glands, thyroid). In order to reduce patient exposure, lower power preview scans are typically used to identify the region of interest and properly position patients in the device. However, the amount of radiation that results from preview scans, as well as their frequency of use in clinical settings, is not well known. An understanding of the quantity of preview scans typically administered to patients prior to the diagnostic scan as well as disclosure of the effective dose associated with these scans will allow for better estimates of risk to patients. Given that the acquisition of previews and scans is routinely delegated to dental technicians, these findings may also potentially inform clinical practice and training procedures.

### 1.2 EFFECTIVE DOSE: SOURCES AND DEFINITIONS

Due to the heterogeneous nature of the human body, both in terms of density and potential for harmful transformation, several methods are used to measure radiation dose. *Exposure* is a measure of radiation quantity produced by a radiation source and is expressed in units of *absorbed dose*, Gray (1 Gy = 100 rad = 1 joule/kilogram). Absorbed dose is a measure of the energy absorbed per unit mass of any type of matter. Given that many tissue types comprise the human body, *equivalent dose* is used to

compare the biologic effects of different types of radiation on specific tissue or organs. It is computed by taking the weighted average of absorbed dose for a tissue or object. The *weighting factor* is dependent on the type and energy of the radiation involved and is expressed in units of Sievert (1 Sv = 100 rem). Thus *effective dose* (ED) is used to estimate the risk in humans and is the weighted average of the equivalent dose to each organ or tissue, based on each tissue's likelihood of damage and eventual transformation. This is also expressed in units of Sievert, or more commonly for CBCT, microsievert ( $\mu$ Sv).

In addition to medical radiation directly caused by imaging techniques, patients are exposed to constant background radiation from well-measured cosmic and terrestrial sources. Cosmic radiation is dependent on elevation and latitude; while it measures about 240  $\mu$ Sv per year at sea level, radiation levels double for every 2000 m of elevation and increases substantially near the Earth's poles due to deflection by the Earth's magnetic field. For example, long flights by airplane incur an increased dose because of increased altitude and a five-hour flight is the equivalent of a year of cosmic radiation at sea level (White 2009). By far, the largest contributor to background radiation is terrestrial; Radon, a decay product of Uranium, exists as a trace contaminant in water and soil and accounts for over half of the yearly background dose (2000  $\mu$ Sv). In total, all background radiation experienced by the average inhabitant in the United States from natural sources measures around 3000  $\mu$ Sv.

The International Commission on Radiological Protection (ICRP) provides weighting factors for various anatomic sites in order to determine the effective dose of radiation on the human body from different sources. These data are based on epidemiologic findings of radiation exposure levels and incidences of tissue cancer across populations. The most recent recommendations from 2007 are included in Table

1.1. Relevant remainder tissues include extrathoracic airway tissue, lymphatic nodes, and oral mucosa.

**Table 1.1. ICRP 2007 recommended tissue weighting factors.**

Tissue	Tissue weighting factor	Sum of weighting factors
Bone-marrow, colon, lung, stomach, breast, remainder tissues	0.12	0.72
Gonads	0.08	0.08
Bladder, esophagus, liver thyroid	0.04	0.16
Bone surface, brain, salivary glands, skin	0.01	0.04
Total		1.00

### 1.3 MEASURING EFFECTIVE DOSE

In order to assess effective dose of medical radiation sources, an artificial stand-in for a human (called a “phantom”) simulates tissue densities with holes for sensors in areas of sensitive tissues. The effective dose is calculated by multiplying the exposure of each sensor (usually 20-40 placed in relevant sensitive tissues) by each tissue weighting factor and summing across all sensors:

$$\sum W_T \cdot H_T \quad (1.1)$$

$W_T$  = tissue weighting factor  
 $H_T$  = weighted tissue dose

While computational methods may be used to approximate this method, phantom measurements represent the standard for obtaining information on effective dose (Dixon 2010).

Various sensors have been used in anthropomorphic (human-shaped) and acrylic phantoms to measure effective dose; historically, the most popular is the thermoluminescent dosimeter (TLD). Although these sensors are relatively inexpensive and reusable, they require extensive thermocycling to initialize as well as a separate

reading apparatus to record measured dose (Qu 2010). TLDs offer advantages in terms of sensitivity, as they accurately accumulate dose over time such that even very low exposures can be measured given an adequate number of scans. In general, TLDs require doses above a threshold of 10,000  $\mu$ Gy (Schieck 2010). More recent sensor technology utilizes metal-oxide semiconductor field-effect transistors (MOSFET) that allow for the real-time measurement of radiation exposure with accuracy comparable to TLDs (Koivisto 2013). These commercially available dosimeters show low radiographic profile and demonstrate sensitivity at doses as low as 100  $\mu$ Gy, but exposure-specific calibration and beam-angle dependence may encumber their ease of use (Cheung 2009, Manninen 2014).

To allow for different examinations and imaging resolutions, CBCT manufacturers offer variable beam parameters (kV, mA) and field of view (FOV) settings. Previous studies have measured the effective dose of nearly all devices and FOVs using TLDs embedded in anthropomorphic phantoms (Bornstein 2014). Taken together, their findings suggest that the same FOV results in a ten-fold difference in effective dose between manufacturers, with child-sized phantoms showing even greater doses when subjected to large volume scans due to increased proximity of a child's thyroid gland to the center of the beam (Qu 2012) (Table 1.2). Although reducing the FOV and resolution to the minimum required for diagnostic purposes reduces the effective dose of the examination, the use of conservative settings may require extra technician training; further, it has been shown that higher doses reduce noise and improve image quality (Ludlow 2006).

Few comprehensive studies have used MOSFET dosimeters, due to the cost of the system and delayed adoption of the newer technology. To our knowledge, no previous studies have evaluated the effective dose of the preview scans used to position patients. In fact, most studies tend to include one preview scan with the dose from each

diagnostic scan with the assumption that a single preview scan is typically taken prior to the full scan in clinical settings, resulting in a “small” extra dose (Ludlow 2013).

**Table 1.2. Effective doses from imaging (from Bornstein 2014).**

Exam	Effective dose ( $\mu\text{Sv}$ )	Study
15 x 11 cm <sup>2</sup> Panoramic	10	Silva 2008
18 x 15 cm <sup>2</sup> Cephalometric	10	Silva 2008
16 x 13 cm <sup>2</sup> iCAT Next Gen	87 (adult) 134 (10 year old)	Ludlow 2008, Theodorakou 2012
23 x 17 cm <sup>2</sup> i-CAT Next Gen	74-78	Ludlow 2008, Davies 2012
20 x 20 cm <sup>2</sup> CB Mercuray	1073	Ludlow 2008

## **Chapter 2. OBJECTIVES**

### **2.1 STUDY AIMS**

This study aimed to measure the effective dose of positioning/preview scans for five CBCT devices used in dentistry.

### **2.2 STUDY HYPOTHESES**

The effective dose from CBCT preview scans are measurable and contribute significantly to the total dose received by patients from the imaging process.

### **2.3 NULL HYPOTHESES**

Effective dose from CBCT preview scans will not be measurable or contribute meaningfully to the total dose received from imaging (with any reasonable number of previews).

## Chapter 3. MATERIALS AND METHODS

### 3.1 EXPERIMENTAL DESIGN

#### 3.1.1 *Dose Phantom*

A radiation analog dosimetry phantom (RANDO) was used to obtain effective dose measurements. This phantom is constructed from tissue equivalent skull materials surrounded by appropriate tissue equivalent structures. There are ten axial layers with a grid of holes for the placement of dosimeters or tissue-equivalent plugs.

#### 3.1.2 *Dosimeters*

The mobileMOSFET system uses metal-oxide semiconductor field-effect transistor (MOSFET) dosimeter technology. The setup includes five readers (mobileMOSFET, Model TN-RD-16, Best Medical Canada, Ottawa, ON, Canada) with five micro MOSFET dosimeters each (microMOSFET, Model TN-1002RDM-H, Best Medical Canada, Ottawa, ON, Canada), for a total of 25 observation points. The dosimeters and readers connect wirelessly to a laptop via a Bluetooth™ transceiver. After the dosimeters are initialized, the dose is accumulated in the dosimeter as a voltage differential and read immediately following the completion of the desired number of scans.

The MOSFET sensors translate a voltage difference to an absorbed dose using a conversion factor measured semi-annually by Medical Physics staff for each sensor and reader assembly. Conversion factors for the current study were determined by irradiating the dosimeters at 80 kVp, 200 mAs, and 40 cm<sup>2</sup> using a calibrated source (Xi, Model 8201023-D, Unfors Raysafe, Billdal, Sweden) and were based on the following equation:

$$CF = mV/Gy \quad (3.1)$$

Where CF is the conversion factor to be measured, mV is the voltage difference measured in the dosimeter, and Gy is the standardized dose absorbed from the standard source. Dosimeters were placed in the axial layers and sensitive tissue areas described previously (Ludlow 2008).

Effective dose, expressed in  $\mu\text{Sv}$ , was calculated using equation 1.1. Tissue weighting factors ( $W_T$ ) and fractions irradiated (Table 3.1) were based on ICRP recommendations (Valentine, 2007) and the work of Roberts (2009).

**Table 3.1. Phantom slices, tissues, and sensor locations.**

Organ	$W_T$	Locations (number of sensors)	Level
Bone marrow	0.12	Calavarium anterior/left/posterior (3)	2
Bone surface	0.01	Cervical spine, mandible ramus (3)	6
		Mandible body (2)	7
Brain	0.01	Mid brain (1)	2
		Pituitary fossa (1)	3
Eyes		Orbits, lenses of eye (4)	4
Salivary glands	0.01	Parotid gland (2)	6
		Submandibular/sublingual glands (3)	7
Thyroid	0.04	Thyroid surface/midline (2)	9
Skin	0.01	Right cheek (1)	5
		Left back of neck (1)	7
Esophagus	0.04	Pharyngeal-esophageal space (1)	9
Remainder	0.12	extrathoracic airway tissue, lymphatic nodes, and oral mucosa	

### 3.1.3 CBCT Scanners

The phantom was positioned, exposed to 50 preview scans, and the effective dose measured for each of the devices and FOVs studied (Table 3.2). Next, while maintaining the position of the phantom, a full three-dimensional scan and exposure reading were taken. Standard cephalometric and panoramic radiographs were also measured as a basis for comparison using 50 and five exposures, respectively.

Table 3.2. Devices and settings.

Device	FOV (cm x cm)	kV	mA	Time (sec)
Accuitomo 170	8 x 8	90	7	17.5
Accuitomo 170	6 x 6	90	6	17.5
Accuitomo 170	4 x 4	90	6	17.5
Planmeca Promax 3D	23 x16	96	11	9
Carestream 9300	17 x13.5	90	4	11.3
i-CAT Next Generation	23 x17	90	7	17.8

## 3.2 DEVICE LOG FILES

In order to conveniently store acquisition data, CBCT devices interface with a nearby personal computer through a serial data port. Detailed logs of events (e.g., preview and full scans) are automatically generated by the software for troubleshooting purposes and written to timestamped files. Given earlier findings demonstrating that preview scans taken by i-CAT and Accuitomo devices exhibit the highest effective doses of the five examined, efforts were focused on obtaining historical preview/full scan data from the corresponding software.

### 3.2.1 *i-CAT Log Files*

Careful examination of the file structure written to disk by i-CAT software revealed text files with the following pathnames:

```
C:\Program Files\Imaging Sciences International\iCAT Software\  
ISIApplication_MMDDYYYY.log.
```

The i-CAT software generates time-stamped text files devoid of identifying patient data and records all user actions. Log files from March 2013 to February 2015 were gathered for inclusion in the study sample. These files were filtered with search strings in order to identify preview scans, full scans, and field of view information recorded over the past

two years, comprising over 4000 events. The example log file shown in Figure 3.1 records the user executing two  $23 \times 17 \text{ cm}^2$  previews and full scan for patient #1992.

```
1992 09/24/2014 13:27:39.015 WARNING | CT PREVIEW CONFIRMED*****
1992 09/24/2014 13:27:39.015 INFO | PhysicalCube (x,y,z) = 230,230,170
1992 09/24/2014 13:27:59.812 WARNING | CT PREVIEW CONFIRMED*****
1992 09/24/2014 13:27:59.812 INFO | PhysicalCube (x,y,z) = 230,230,170
1992 09/24/2014 13:28:26.109 CCTDlg::OnBnClickedButtonCapture: start
1992 09/24/2014 13:28:31.796 WARNING | CT SCAN CONFIRMED*****
1992 09/24/2014 13:28:31.796 INFO | PhysicalCube (x,y,z) = 230,230,170
```

Figure 3.1. Example of log file text generated for two previews and a full scan for patient 1992 on 24 September 2014.

### 3.2.2 Accuitomo Log Files

The file structure of the Accuitomo software proved to be far more complex, with several drives and countless inscrutable text log files. Although patient data could be sorted easily within the software, these data could not be exported and the database resided on a standalone computer in the endodontic department. After many failed attempts to sort the text files and find relevant events, a time-stamped file structure was found within a server drive containing images for previews and full scans in Joint Photographic Experts Group (.jpg) format and proprietary packaged (.pak) files (Figure 3.2). The .jpg files represented the “thumbnail” images generated by the software to display patient images on a single page. As a result, their file sizes were small enough to be exported easily for use in the current study, while still detailed enough to allow for visual examination and removal of non-relevant scans (e.g. CBCT images of models and splints). A month’s worth of historical data were obtained and successfully matched to the device’s proprietary viewing software. This confirmed that the thumbnail images represented a complete history of the device starting in 2011.

During acquisition of experimental data, it was observed that there were only two sizes of preview across the three device settings: one large size for the  $8 \times 8 \text{ cm}^2$  FOV and one medium size for the  $6 \times 6 \text{ cm}^2$  or  $4 \times 4 \text{ cm}^2$  FOV. Subsequent review of preview

images in the database revealed only two thumbnail image resolutions: 422 x 224 pixels and 422 x 185 pixels. The Accuitomo device does not directly store the machine settings for saved preview images, but by comparing these data to experimental data gathered previously, it was determined that the two thumbnail sizes corresponded in all cases to the large ( $8 \times 8 \text{ cm}^2$ ) and medium ( $6 \times 6 \text{ cm}^2$ ,  $4 \times 4 \text{ cm}^2$ ) preview sizes, respectively.

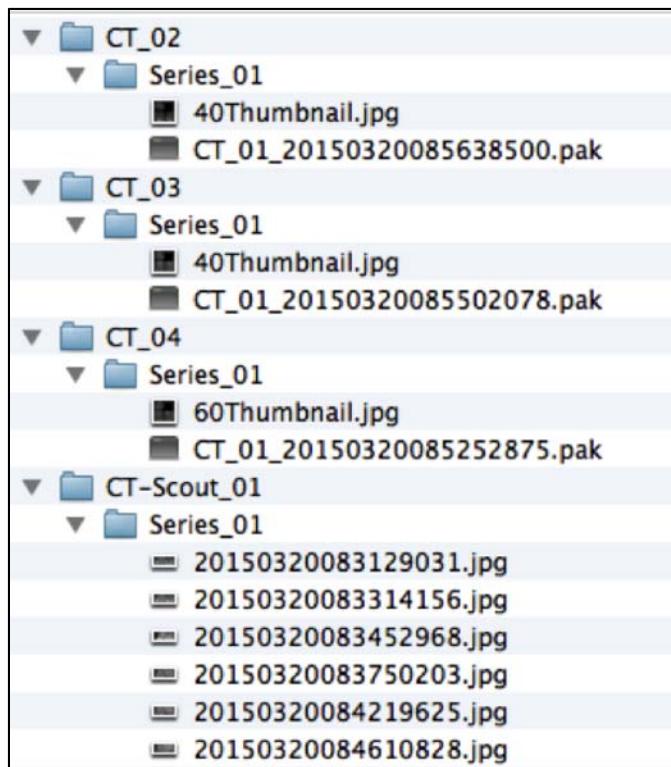


Figure 3.2. Three full scans and six scout images taken for one patient between 0831 and 0856 on 20 March 2015. Note: Timestamp format: YYYYMMDDHHHH.

### 3.3 FIGURES OF MATERIALS AND METHODS

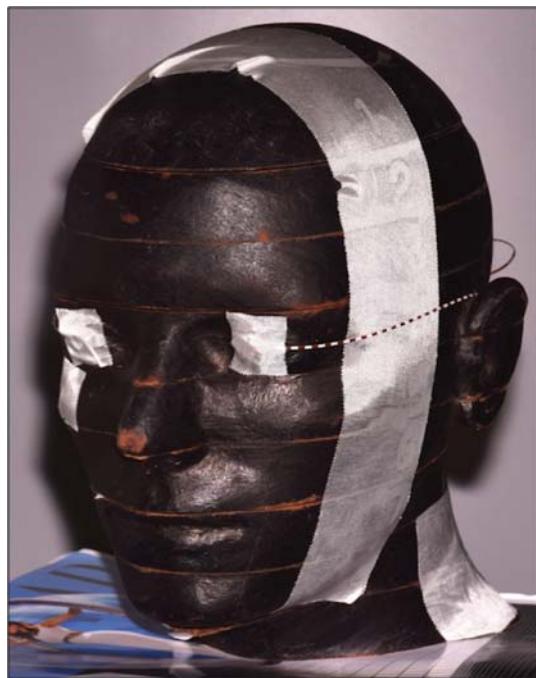


Figure 3.3. RANDO Phantom.



Figure 3.4. i-CAT Next Generation imaging setup.

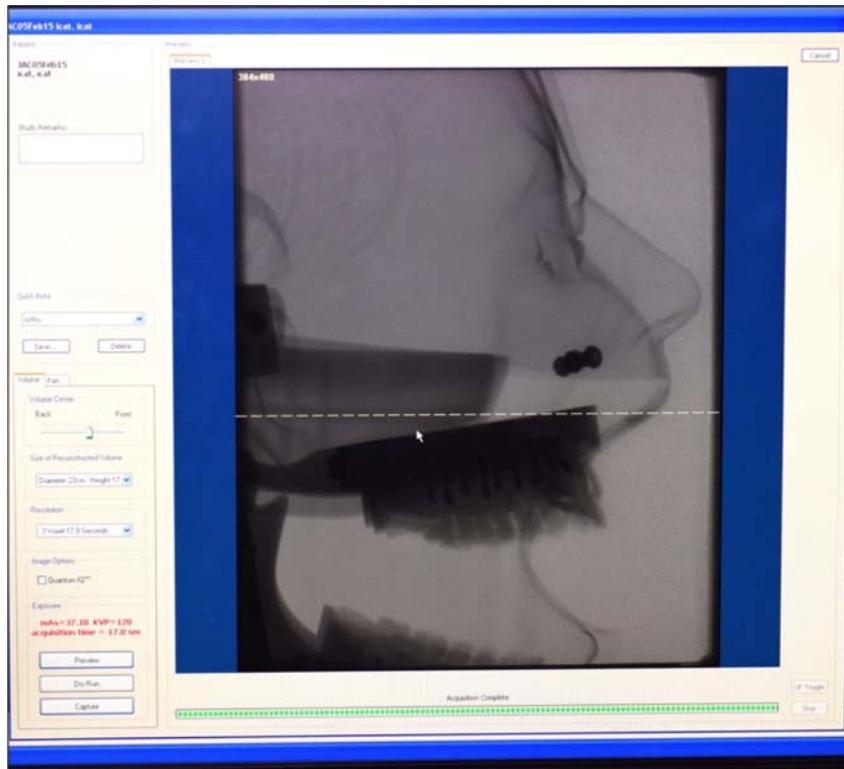


Figure 3.5. i-CAT Next Generation sample preview.



Figure 3.6. Accuitomo 170 imaging setup.



Figure 3.7. Accuitomo 170 sample preview.

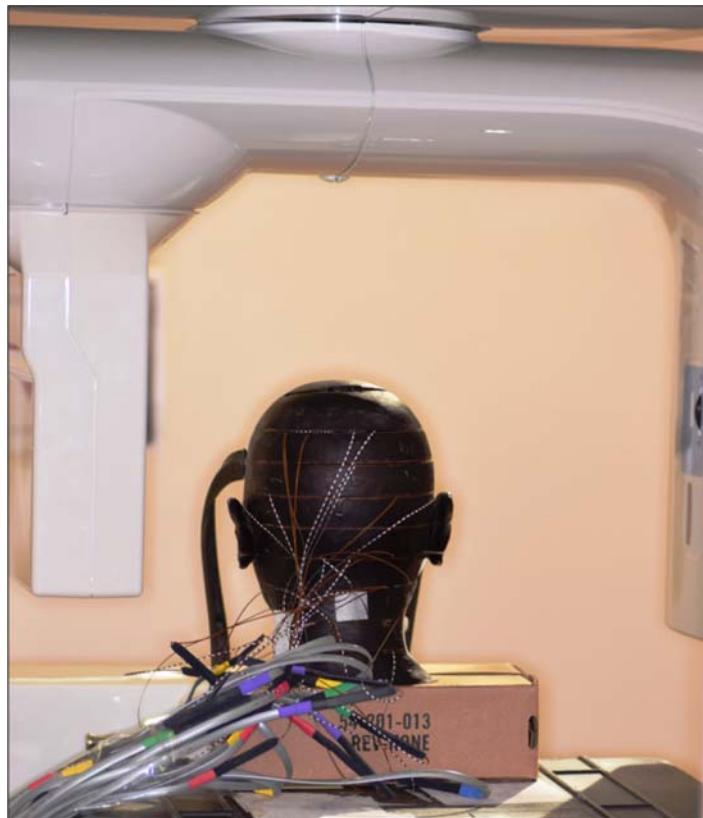


Figure 3.8. Carestream 9300 imaging setup.



Figure 3.9. Carestream 9300 sample preview.



Figure 3.10. Planmeca Promax 3D imaging setup.



Figure 3.11. Planmeca Promax 3D sample preview.



Figure 3.12. i-CAT FLX 3D sample preview

## Chapter 4. RESULTS

### 4.1 PREVIEW AND FULL SCAN EFFECTIVE DOSE

Effective doses for a single full CBCT scan from the Accuitomo, Planmeca, Carestream, and i-CAT devices were calculated using Equation 1.1 and absorbed dose measurements obtained with MOSFET dosimeters (Figure 4.1). In order to accurately measure the effective dose of a single exposure to a lower power preview/positioning scan given limitations in dosimeter sensitivity, effective doses of a total 50 consecutive scans with each device were measured, and then divided by 50 to arrive at an average for a single scan (Figure 4.2).

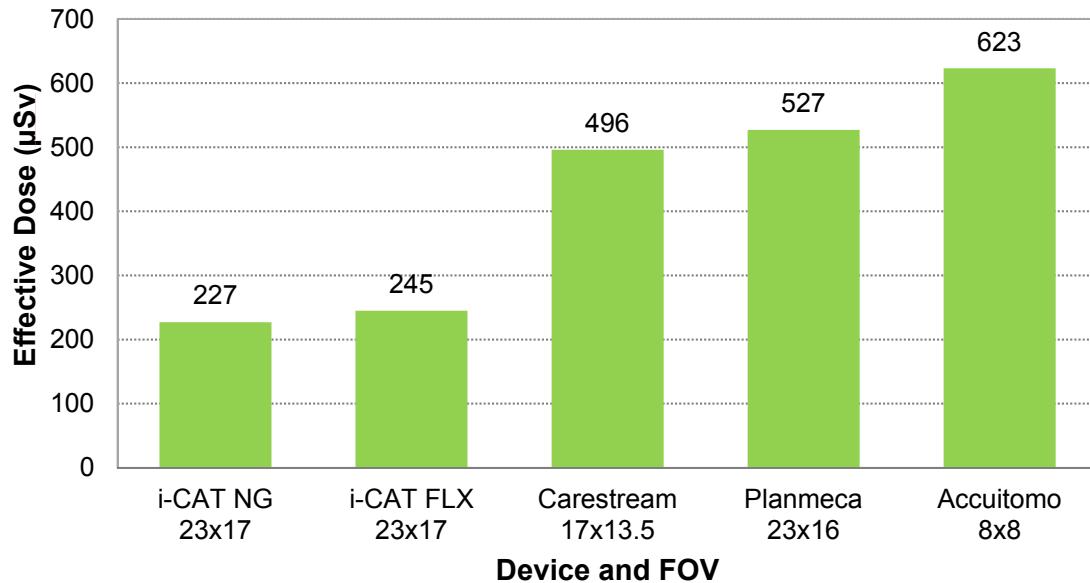


Figure 4.1. Full scan effective doses by device and field of view specification.

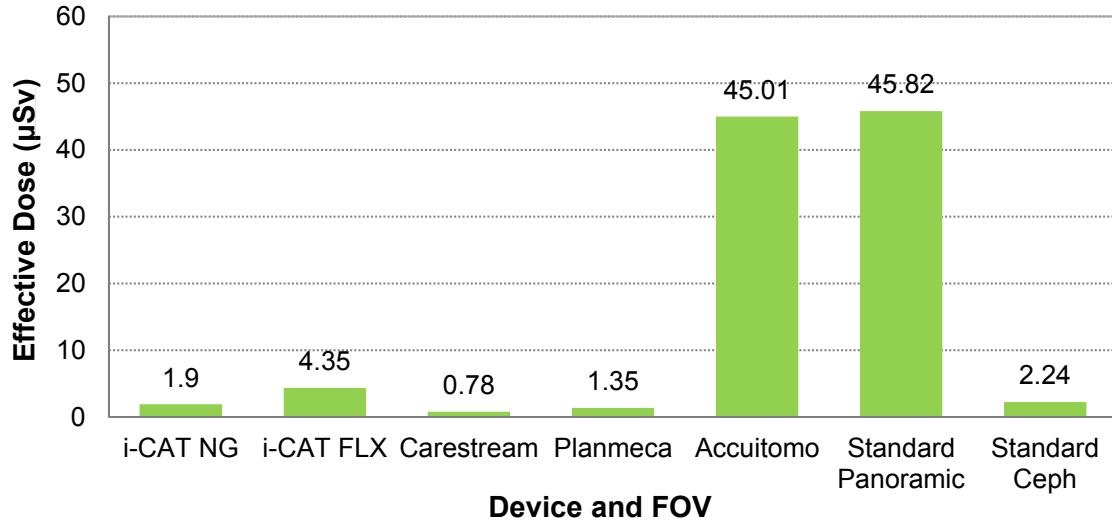


Figure 4.2. Preview scan effective doses by device and field of view specification.

#### 4.2 EFFECTIVE DOSES COMPARED TO STANDARD CEPHALOMETRIC AND PANORAMIC RADIOGRAPHS

Effective dose of a single exposure to a standard cephalometric or panoramic radiograph were calculated by collecting a total of five panoramic and 50 cephalometric radiographs, respectively, and dividing the total dose by the exposure count (Figure 4.3).

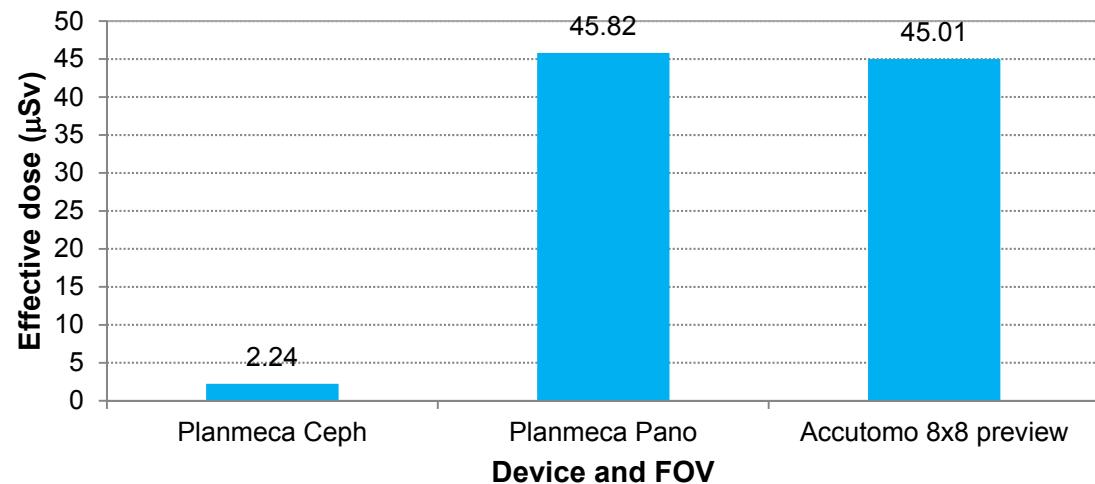


Figure 4.3. Effective doses of Planmeca standard cephalometric and panoramic radiographs versus Accuitomo  $8 \times 8 \text{ cm}^2$  preview radiograph.

In order to better qualify the effective doses of the preview scans in a clinically relevant way, values were compared to the dose of a single standard cephalometric image. The scale was adjusted in order to better display the doses of the lower dose devices and fields of view (Figure 4.4).

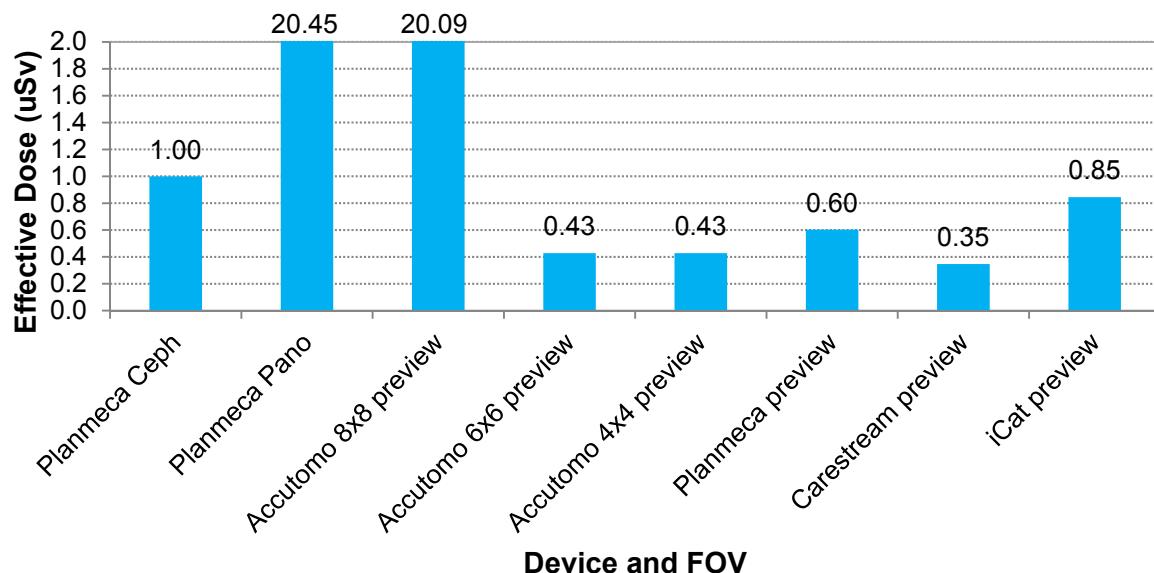


Figure 4.4. Preview scan data and panoramic radiograph effective doses relative to a single standard cephalometric radiograph. Note: The effective doses displayed for the panoramic and Accumoto 8 x 8 cm<sup>2</sup> are not to scale.

#### 4.2.1 Counting i-CAT Previews Per Full Scan

Log files were combined and sorted to isolate preview/full scan actions in chronological order with FOV and non-identifying patient number. The number of previews between each full scan was counted and a histogram was constructed illustrating the frequency of exams binned by number of previews (Figure 4.5). In order to reset the scale, a separate histogram was used to display the frequency of events with greater than seven previews per full scan (Figure 4.6). The average number of previews per full scan was 3.3 for all events over the two-year period.

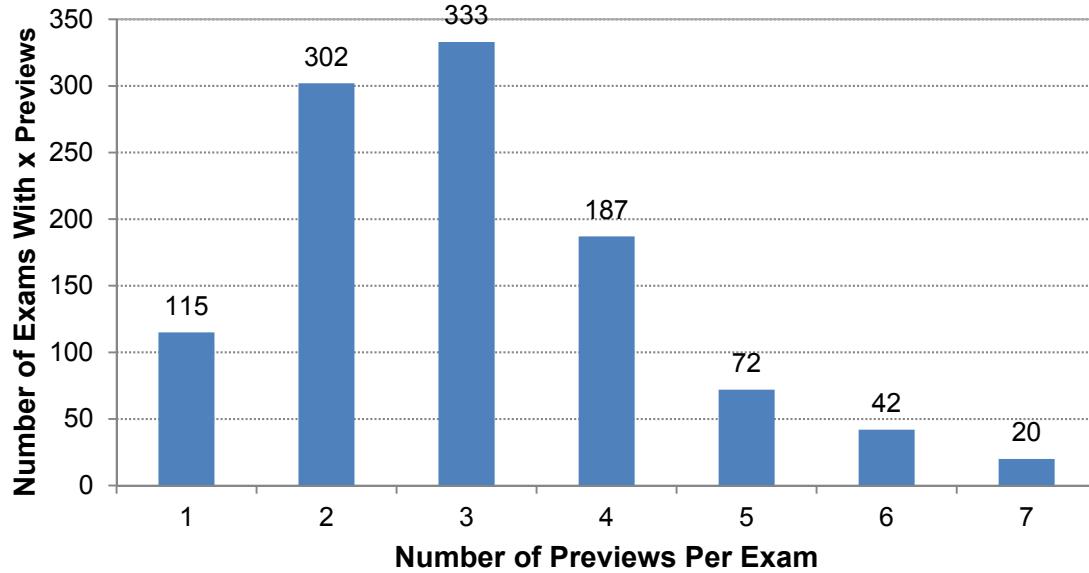


Figure 4.5. Frequency counts for 1-7 previews per full  $23 \times 17 \text{ cm}^2$  i-CAT CBCT.

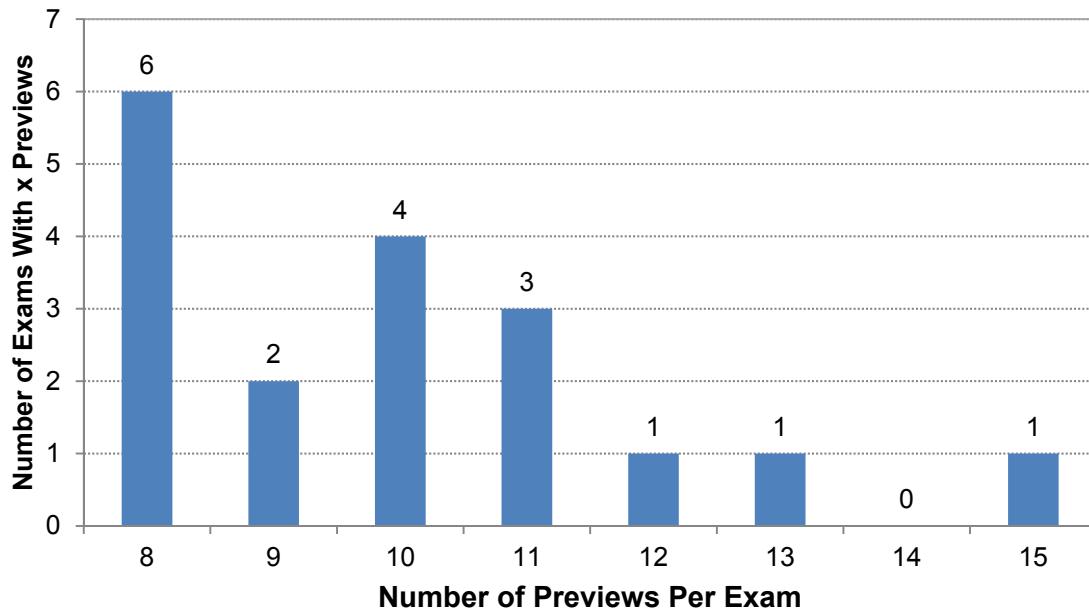


Figure 4.6. Frequency counts for 8+ previews per full  $23 \times 17 \text{ cm}^2$  i-CAT CBCT.

#### 4.2.2 Counting Accuitomo Previews Per Full Scan

The .jpg and .pak image files corresponding to previews and full scans were compiled from the Accuitomo database and viewed. Images with non-patient data (e.g., models

and stents or saved two-dimensional slices from the CBCT) were removed from the study sample. Remaining filenames were sorted by time stamp to list preview and full scan actions in chronological order (Figure 4.7). Previews between each full scan were tallied and separate histograms were constructed to display events with (a) three or fewer previews (Figure 4.8) and (b) greater than three previews (Figure 4.9) in order to facilitate interpretability. It was noted that consecutive full scans were occasionally taken for each patient and these events were counted in the same way (Figure 4.10).

422x185	20141112095938437.jpg	SCOUT	453980479
422x185	20141112100125718.jpg	SCOUT	453980479
422x185	20141112100403781.jpg	SCOUT	453980479
422x185	20141112100738062.jpg	SCOUT	453980479
422x185	20141112100912125.jpg	SCOUT	453980479
422x185	20141112101805812.jpg	SCOUT	453980479
422x185	20141112101936343.jpg	SCOUT	453980479
422x185	20141112102046937.jpg	SCOUT	453980479
	20141112102637750.pak	FULL	453980479

Figure 4.7. Example Accuitomo log data for patient #453980479 receiving 8 previews and a CBCT (either  $6 \times 6 \text{ cm}^2$  or  $4 \times 4 \text{ cm}^2$ ).

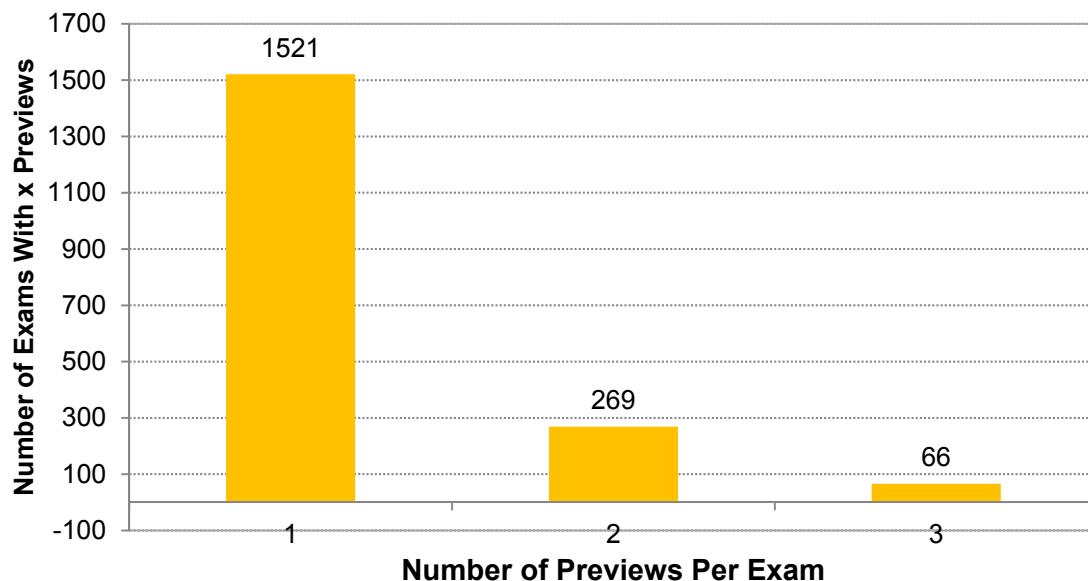


Figure 4.8. Frequency counts for 1-3 previews per full Accuitomo CBCT.

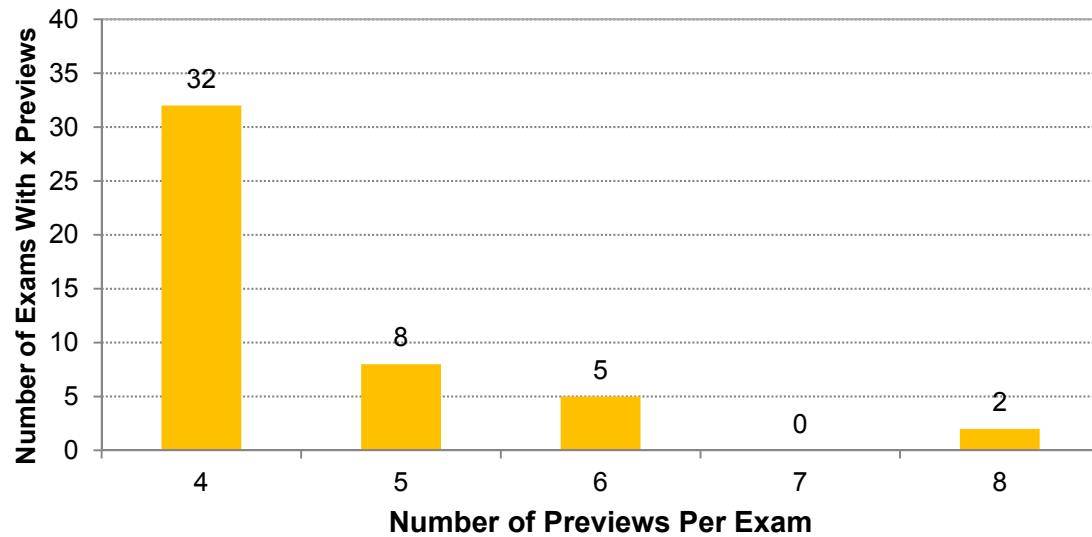


Figure 4.9. Frequency counts for 4+ previews per full Accuitomo CBCT.

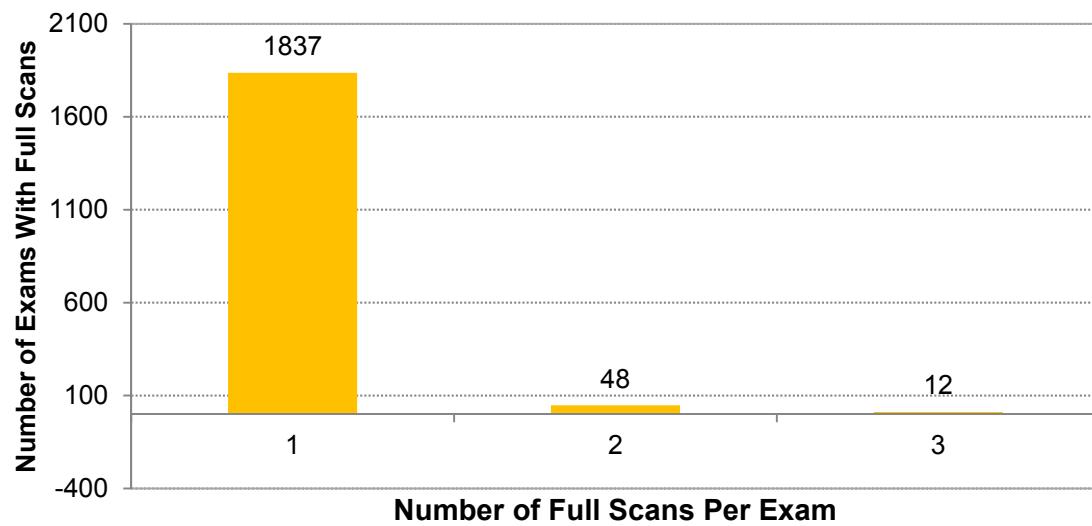


Figure 4.10. Frequency counts for number of full Accuitomo CBCT scans per patient, all fields of view.

## Chapter 5. DISCUSSION

Because of the simplicity of a single exposure for all radiographic treatment planning needs, CBCT devices are becoming more common for diagnosis in orthodontics and dentistry in general. Findings from previous work (White 2009, Bornstein 2014) indicate the dosage of radiation from this technology is low compared to medical computed tomography (CT) and unavoidable yearly doses of background radiation. Despite these reassurances, sensitive tissues still absorb high-energy radiation, incurring risk for transformation with each exposure. This research contributes to the field by quantifying the effective dose from preview/positioning scans, thereby more accurately estimating the dose of a full patient exam. Clinically, these findings have the potential to stimulate discussion regarding the marginal utility of repeated preview scans, shape clinical examination procedures, and improve training for the dental technicians who are routinely tasked with obtaining these images.

### 5.1 EFFECTIVE DOSE OF CBCT FULL SCANS

The effective doses of the CBCT devices and fields of view measured in this study were consistently higher than those measured previously using TLD sensors. This is likely due to the MOSFET dosimeters used in this study, as findings from other work utilizing this newer technology also indicate higher dose measurements compared to TLD dosimeters (Table 5.1).

Because effective dose is a weighted average of absorbed radiation to different tissues, small differences in positioning or size of subject can move sensitive tissues in or out of the center of the conical beam and cause variability in recorded values, providing some explanation for discrepant findings. Previous studies have established the relative invariability of measuring effective dose in a stationary phantom (Ludlow

2006), and nearly all previous studies expose only a single full CBCT to measure effective dose.

In order to reduce measurement error due to positioning, all data in the current study were gathered from a given device in a given field of view without moving the phantom. Background radiation was estimated via a ten-minute acquisition run with the device off and found to be quite low (<15 µSv). In order to examine the reproducibility of effective dose findings, two runs of 50 previews were acquired and compared (Figure 5.1). While absorbed dose measurements varied significantly between runs (up to 60% change at the anterior calavarium), the overall effective dose only differed by around 1%.

**Table 5.1. Effective doses (ED) from two runs using the Accuitomo device.**

Tissue	Run 1 Abs Dose (cGy)	Run 2 Abs Dose (cGy)	% Difference
Esophagus	0.24	0.26	11.06
Thyroid surface left	0.28	0.25	-11.19
Midline thyroid	0.42	0.37	-11.16
Center sublingual gland	1.25	1.19	-4.74
Left submandibular gland	2.87	2.97	3.64
Right submandibular gland	3.57	3.51	-1.81
Left mandibular body	2.16	2.37	9.89
Right mandibular body	3.62	3.57	-1.41
Center cervical spine	0.33	0.39	16.13
Left ramus	1.36	1.5	10.15
Right ramus	0.4	0.41	1.7
Left parotid	0.49	0.48	-0.9
Right parotid	0.55	0.54	-0.99
Left back of neck	4.03	3.92	-2.72
Right cheek	3.47	3.42	-1.38
Left lens of eye	0.16	0.14	-13.37
Right lens of eye	0.3	0.29	-4.8
Left orbit	0.08	0.08	-0.75
Right orbit	0.13	0.12	-8.05
Pituitary	0.08	0.09	14.18
Midbrain	0.06	0.06	6.23
Calvarium anterior	0.03	0.05	60.32
Calvarium left	0.04	0.03	-27.66
Calvarium right	0.04	0.05	21.02
Calvarium posterior	0.06	0.03	-46.21
Average dosimeter	1.04	1.04	0.3
<b>Effective Dose</b>	1436.78	1452.16	1.07

This is due to the nature of the effective dose calculation: large differences measured at sensors detecting low absorbed dose and within low weighted tissues have little effect on the formula's (1.1) result.

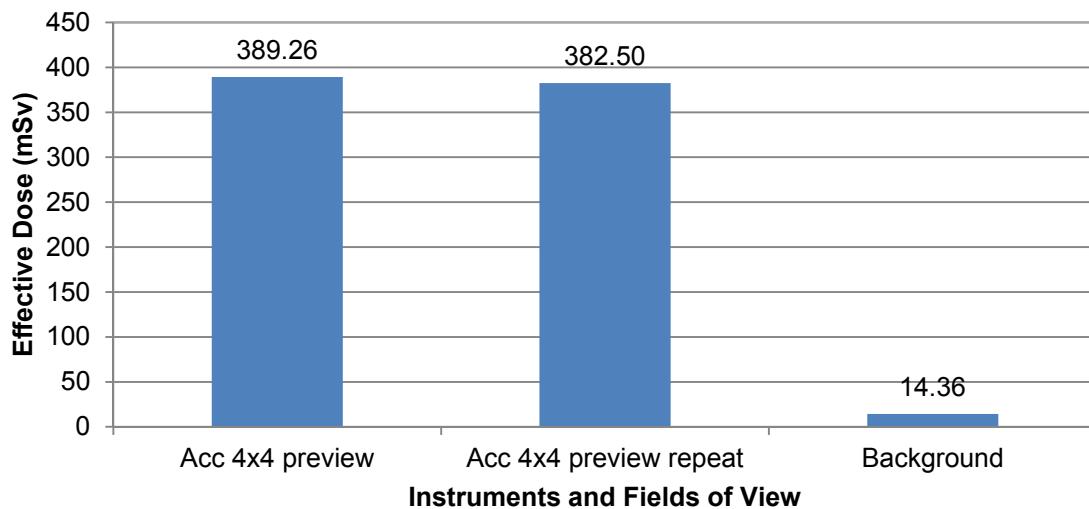


Figure 5.1. Accuitomo 50 preview exposure runs repeated and compared to background measurement.

## 5.2 EFFECTIVE DOSE OF CBCT PREVIEW SCANS

In order to accumulate enough absorbed radiation to obtain measurements at the deepest sites in the phantom, the phantom was exposed to 50 previews using each device and FOV. In general, the data suggested that effective doses resulting from preview scans were low (<2  $\mu$ Sv) and contributed <1% to the total dose from a CBCT exam (Figure 4.1 and Figure 4.2).

However, the notable exception was the 8 x 8 cm<sup>2</sup> field of view preview for the 3D Accuitomo 170. The Accuitomo was unique among the devices in this study because its preview includes exposures and images from two angles: right lateral and anterior (Figure 3.5). This feature of the device was shown to provide over five times the dose to sensors in sensitive regions of salivary tissue and bone marrow (compared to other preview exposures) resulting in a much higher than anticipated effective dose

(Table 5.2). These findings suggest that preview scans using the Accuitomo expose patients to an effective dose equivalent to a panoramic radiograph or twenty standard cephalometric radiographs. However, the extra information from the dual images or the extra contrast provided by the higher dose previews likely contributes to fewer previews taken per patient; while 90% of i-CAT CBCT historical exams were observed to include more than one preview, only 20% of Accuitomo CBCT exams utilized multiple previews (Figure 4.5 and Figure 4.8).

Table 5.2. Comparison of effective dose to individual tissues in Accuitomo previews, 50 exposures at each field of view.

Major Organ	WT	ED ( $\mu$ Sv)	
		Accuitomo $8 \times 8 \text{ cm}^2$ preview	Accuitomo $4 \times 4 \text{ cm}^2$ preview
Bone marrow	0.12	1176.70	153.35
Thyroid	0.04	66.80	17.98
Esophagus	0.04	10.28	2.44
Skin	0.01	4.91	0.98
Bone surface	0.01	98.06	12.78
Salivary glands	0.01	512.30	65.20
Brain	0.01	12.66	3.70
Remainder	0.12	368.99	60.38
<b>Effective Dose</b>		<b>2250.69</b>	<b>316.80</b>

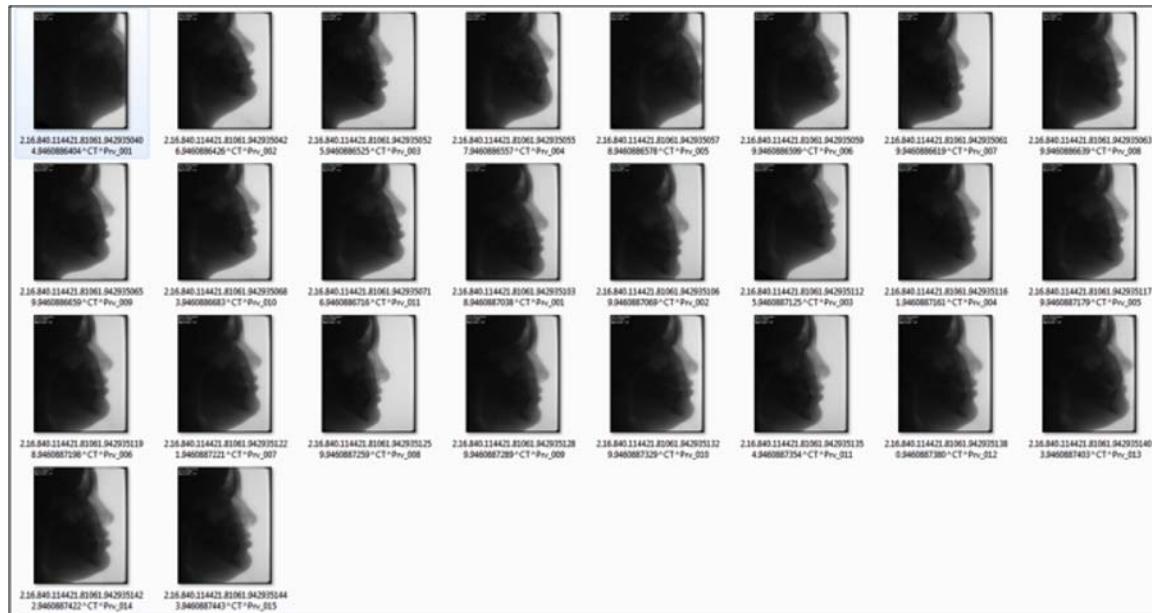
### 5.2.1 *i*-CAT Previews Per Full CBCT Scan

The dose of a radiographic exam is the effective dose of the full CBCT scan plus all previews required to position the patient. Based on data gathered from the i-CAT log files from March 2013 to February 2015, technicians using the i-CAT device required an average of 3.3 previews to position the patient for the largest full scan. When the less common smaller FOVs were considered for this device, an average of 3.0 previews were required per full scan (Table 5.3). Conventional wisdom suggests that preview scans expose patients to a nominal level of radiation. Results from the current study suggest that the effective dose contributed by an average of three preview exposures is <3% of the effective dose of the exam (Figure 4.1 and Figure 4.2). Thus, a total of 12 previews

would be needed to contribute to 10% to the total effective dose of the exam; of the over 1040 historical examinations surveyed, this occurred for only three exams (Figure 4.5 and Figure 4.6). However, one patient received 26 previews and two full scans over 17 minutes, so higher preview counts do happen occasionally (Figure 5.2), although the cause of such excessive scans is unknown.

**Table 5.3. Previews per full scan for different devices and fields of view.**

Device	FOV (cm <sup>2</sup> )	Previews per full scan	Number of preview scans
i-CAT Next Generation	Largest only (23 x 17)	3.25	3397
i-CAT Next Generation	All but largest (16 x 13, 16 x 10, 16 x 8, 16 x 6, 8 x 8)	2.98	253
3D Accuitomo 170	Large only (8 x 8)	1.88	308
3D Accuitomo 170	All (8 x 8, 6 x 6, 4 x 4)	1.30	2471



**Figure 5.2. Collage of i-CAT images of a single patient who received two full scans and 26 previews over 17 minutes.**

### 5.2.2 Accuitomo Previews Per Full CBCT Scan

The Accuitomo software does not store FOV data in either thumbnail images or navigation software; therefore, the size of FOV was inferred based on the resolution of

the image, a relationship confirmed by comparing the server database images to experimental data of known FOV. This relationship was true for the preview exposures/images, but the full scan FOV data was inferred from the preview dimensions. Given that there are only two sizes of preview for the three full scan dimensions, it was not possible to separate the  $6 \times 6 \text{ cm}^2$  from the  $4 \times 4 \text{ cm}^2$  data. It is certainly possible that one could take a preview of a given size and then a full scan of another size, and this would go undetected. However, the device also requires a full patient repositioning if the technician attempts to switch between the largest field of view ( $8 \times 8 \text{ cm}^2$ ) and either of the smaller fields of view ( $6 \times 6 \text{ cm}^2$ ,  $4 \times 4 \text{ cm}^2$ ), so switching FOVs between previews full scan must be rare.

Between January 2012 and April 2015, technicians using the Accuitomo device required only 1.3 previews to position the patient for a full scan. When the larger  $8 \times 8 \text{ cm}^2$  FOV was separated from the data, it was observed that 1.8 previews were required to position the patient. However, large FOV scans represented only 11% of previews taken on the device in this three-year period (Table 5.3).

Because all images were inspected visually, it became apparent that some patients received multiple full scans as well as multiple previews, and these events were counted as well for the Accuitomo device (Figure 5.). Two or more consecutive full scans were acquired only 60 times on the Accuitomo device (<4% of the exams).

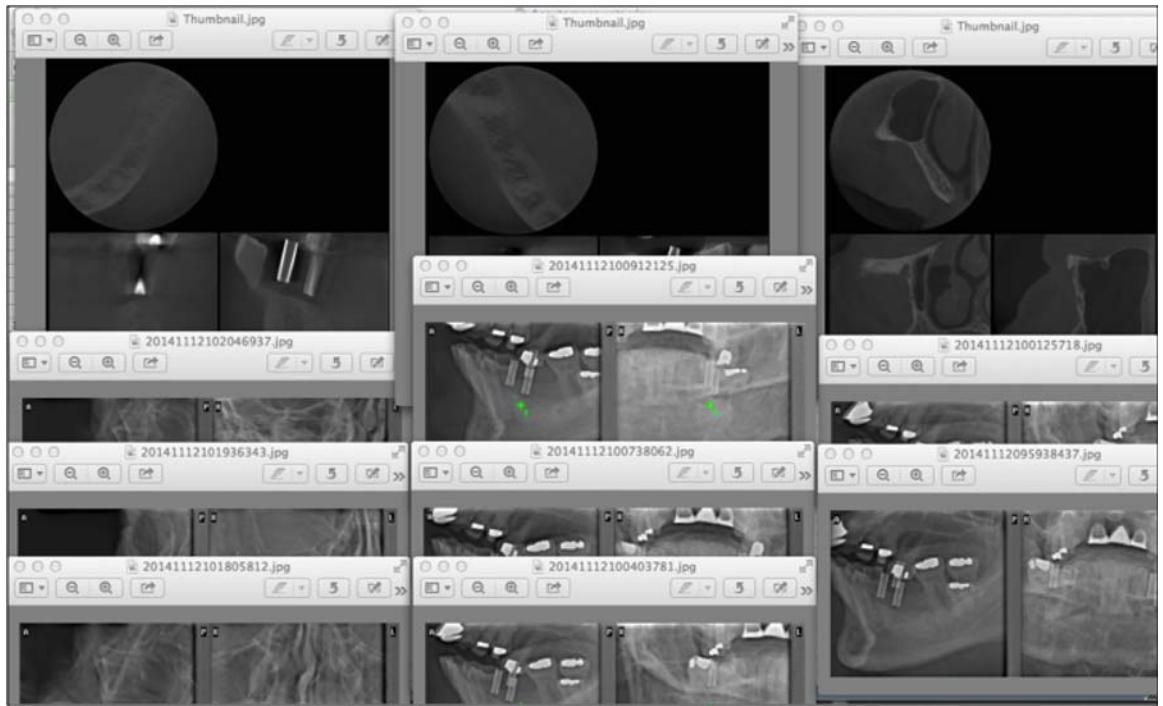


Figure 5.3. Collage of Accuitomo images of a single patient who received three full scans and eight previews over 21 minutes.

## Chapter 6. STUDY CONCLUSIONS

1. Using the MobileMOSFET system, preview scans for all five devices selected are measurable above background noise and contribute between <1% and 7.2% to the total imaging dose per preview.
2. The Accuitomo device delivered higher doses for both full and preview scans than other devices, with the 8 x 8 cm<sup>2</sup> preview scan resulting in effective doses measuring as high as 45 µSv (equivalent to twenty standard cephalometric radiographs or one panoramic radiograph).
3. The Accuitomo device displays both lateral and frontal previews and requires around a third of the number of preview scans to position the patient compared to the i-CAT device, which uses only a lateral preview.
4. Despite training and experience, dental technicians occasionally expose patients to higher than expected doses of radiation for CBCT exams. This effect is magnified by devices with higher dose preview and full scans.

## APPENDICES

### Appendix A. Raw MOSFET measurements and effective dose calculations

**Table A.1.** Accumoto full scan 8 x 8 cm<sup>2</sup>.

Dosimeter		Voltage (mV)	Dose (Gy)	Tissue
1	#1-1:	5.1	0.00112	Esophagus
2	#1-2:	3.29	8.34E-04	Left thyroid surface
3	#1-3:	3.28	8.04E-04	Midline thyroid
4	#1-4:	34.54	0.00768	Center sublingual gland
5	#1-5:	51.11	0.0119	Left submandibular gland
6	#2-1:	55.73	0.011	Right submandibular gland
7	#2-2:	20.32	0.00439	Left mandible body
8	#2-3:	19.38	0.00408	Right mandible body
9	#2-4:	17.38	0.00421	Center cervical spine
10	#2-5:	16.96	0.00417	Left ramus
11	#3-1:	21.01	0.00431	Right ramus
12	#3-2:	40.22	0.00897	Left parotid
13	#3-3:	33.56	0.00729	Right parotid
14	#3-4:	4.76	0.0012	Left back of neck
15	#3-5:	34.26	0.00843	Right cheek
16	#4-1:	5.3	0.00121	Left lens of eye
17	#4-2:	5.21	0.00122	Right lens of eye
18	#4-3:	9.43	0.00198	Left orbit
19	#4-4:	6.9	0.00163	Right orbit
20	#4-5:	2.8	6.26E-04	Pituitary
21	#5-1:	1.5	3.97E-04	Midbrain
22	#5-2:	1.2	2.91E-04	Anterior calvarium
23	#5-3:	0.96	2.37E-04	Left calvarium
24	#5-4:	1.05	2.96E-04	Right calvarium
25	#5-5:	1.17	2.61E-04	Posterior calvarium

Table A.2. Accumoto full scan 8 x 8 cm<sup>2</sup>.

Major Organ and Tissue	Irradiation Fraction	Dosimeter	Sums	H <sub>T</sub> ( $\mu$ Sv)	W <sub>T</sub>	ED ( $\mu$ Sv)
<b>Bone marrow</b>	16.5		0.008722	0.001439	0.12	172.70
Mandible	1.3	7,8,10,11	0.004238	0.000055		
Calvarium	11.8	22,23,24	0.000275	0.000032		
Cervical spine	3.4	9	0.004210	0.000143		
<b>Thyroid</b>	100	2,3	0.000819	0.000819	0.04	32.76
<b>Esophagus</b>	10	1	0.001120	0.000112	0.04	4.48
<b>Skin</b>	5	16,17, 14,15	0.003015	0.000151	0.01	1.51
<b>Bone Surface</b>	16.5		0.008722	0.001439	0.01	14.39
Mandible	1.3	7,8,10,11	0.004238	0.000055		
Calvarium	11.8	22,23,24	0.000275	0.000032		
Cervical spine	3.4	9	0.004210	0.000143		
<b>Salivary Glands</b>	100		0.027260	0.027260	0.01	272.60
Parotid	100	12,13	0.008130	0.008130		
Submandibular	100	5,6	0.011450	0.011450		
Sublingual	100	4	0.007680	0.007680		
<b>Brain</b>	100	20,21	0.000512	0.000512	0.01	5.12
<b>Remainder</b>			0.011654	0.000994	0.12	119.29
Lymphatic nodes	5	1, 3-13	0.005827	0.000291		
Muscle	5	1, 3-13	0.005827	0.000291		
Extrathoracic airway	100	18,19, 1, 3-13	0.005252	0.005252		
Oral mucosa	100	4-8,10-13	0.007088	0.007088		
<b>Pituitary</b>	100	20	0.000626	0.000626		
<b>Eyes</b>	100	16-19	0.001510	0.001510		
				<b>Effective dose</b>		<b>622.84</b>

Table A.3. Accuitomo 50 preview scans 8 x 8 cm<sup>2</sup>.

Dosimeter		Voltage (mV)	Dose (Gy)	Tissue
1	#1-1:	11.78	0.00257	Esophagus
2	#1-2:	5.54	0.0014	Left thyroid surface
3	#1-3:	7.94	0.00194	Midline thyroid
4	#1-4:	87.93	0.0196	Center sublingual gland
5	#1-5:	23.24	0.00541	Left submandibular gland
6	#2-1:	154.62	0.0304	Right submandibular gland
7	#2-2:	129.32	0.0279	Left mandible body
8	#2-3:	130.62	0.0275	Right mandible body
9	#2-4:	129.54	0.0314	Center cervical spine
10	#2-5:	110.71	0.0272	Left ramus
11	#3-1:	131.78	0.0271	Right ramus
12	#3-2:	35.16	0.00785	Left parotid
13	#3-3:	90.33	0.0196	Right parotid
14	#3-4:	11.71	0.00296	Left back of neck
15	#3-5:	136.14	0.0335	Right cheek
16	#4-1:	4.35	9.93E-04	Left lens of eye
17	#4-2:	7.7	0.00181	Right lens of eye
18	#4-3:	9.11	0.00191	Left orbit
19	#4-4:	12.97	0.00306	Right orbit
20	#4-5:	6.91	0.00154	Pituitary
21	#5-1:	3.76	9.91E-04	Midbrain
22	#5-2:	1.95	4.72E-04	Anterior calvarium
23	#5-3:	2.45	6.09E-04	Left calvarium
24	#5-4:	2.59	7.32E-04	Right calvarium
25	#5-5:	0.21	4.62E-05	Posterior calvarium

Table A.4. Accuitomo 50 preview scans 8 x 8 cm<sup>2</sup>.

Major Organ and Tissue	Irradiation Fraction	Dosimeter	Sums	H <sub>T</sub> ( $\mu$ Sv)	W <sub>T</sub>	ED ( $\mu$ Sv)
<b>Bone marrow</b>	16.5		0.059429	0.009806	0.12	1176.70
Mandible	1.3	7,8,10,11	0.027425	0.000357		
Calvarium	11.8	22,23,24	0.000604	0.000071		
Cervical spine	3.4	9	0.031400	0.001068		
<b>Thyroid</b>	100	2,3	0.001670	0.001670	0.04	66.80
<b>Esophagus</b>	10	1	0.002570	0.000257	0.04	10.28
<b>Skin</b>	5	16,17, 14,15	0.009816	0.000491	0.01	4.91
<b>Bone Surface</b>	16.5		0.059429	0.009806	0.01	98.06
Mandible	1.3	7,8,10,11	0.027425	0.000357		
Calvarium	11.8	22,23,24	0.000604	0.000071		
Cervical spine	3.4	9	0.031400	0.001068		
<b>Salivary Glands</b>	100		0.051230	0.051230	0.01	512.30
Parotid	100	12,13	0.013725	0.013725		
Submandibular	100	5,6	0.017905	0.017905		
Sublingual	100	4	0.019600	0.019600		
<b>Brain</b>	100	20,21	0.001266	0.001266	0.01	12.66
<b>Remainder</b>			0.038078	0.003075	0.12	368.99
Lymphatic nodes	5	1, 3-13	0.019039	0.000952		
Muscle	5	1, 3-13	0.019039	0.000952		
Extrathoracic airway	100	18,19, 1, 3-13	0.016674	0.016674		
Oral mucosa	100	4-8,10-13	0.021396	0.021396		
<b>Pituitary</b>	100	20	0.001540	0.001540		
<b>Eyes</b>	100	16-19	0.001943	0.001943		
				<b>Effective dose</b>		<b>2250.69</b>

Table A.5. Accuitomo full scan 6 x 6 cm<sup>2</sup>.

Dosimeter		Voltage (mV)	Dose (Gy)	Tissue
1	#1-1:	2.79	6.10E-04	Esophagus
2	#1-2:	1.77	4.49E-04	Left thyroid surface
3	#1-3:	1.84	4.50E-04	Midline thyroid
4	#1-4:	5.4	1.20E-03	Center sublingual gland
5	#1-5:	13.57	0.00316	Left submandibular gland
6	#2-1:	10.99	2.16E-03	Right submandibular gland
7	#2-2:	31.66	6.83E-03	Left mandible body
8	#2-3:	21.69	4.56E-03	Right mandible body
9	#2-4:	10.16	2.46E-03	Center cervical spine
10	#2-5:	23.13	0.00569	Left ramus
11	#3-1:	15.43	3.17E-03	Right ramus
12	#3-2:	11.93	0.00266	Left parotid
13	#3-3:	12.26	2.66E-03	Right parotid
14	#3-4:	4.68	0.00118	Left back of neck
15	#3-5:	20.75	5.11E-03	Right cheek
16	#4-1:	3.28	7.49E-04	Left lens of eye
17	#4-2:	3.38	7.93E-04	Right lens of eye
18	#4-3:	3.79	7.95E-04	Left orbit
19	#4-4:	4.67	1.10E-03	Right orbit
20	#4-5:	1.68	3.76E-04	Pituitary
21	#5-1:	1.37	3.63E-04	Midbrain
22	#5-2:	0.58	1.42E-04	Anterior calvarium
23	#5-3:	0.98	2.43E-04	Left calvarium
24	#5-4:	1	2.82E-04	Right calvarium
25	#5-5:	0.6	1.34E-04	Posterior calvarium

Table A.6. Accuitomo full scan 6 x 6 cm<sup>2</sup>.

Major Organ and Tissue	Irradiation Fraction	Dosimeter	Sums	H <sub>T</sub> ( $\mu$ Sv)	W <sub>T</sub>	ED ( $\mu$ Sv)
<b>Bone marrow</b>	16.5		0.007745	0.001278	0.12	153.35
Mandible	1.3	7,8,10,11	0.005063	0.000066		
Calvarium	11.8	22,23,24	0.000222	0.000026		
Cervical spine	3.4	9	0.002460	0.000084		
<b>Thyroid</b>	100	2,3	0.000450	0.000450	0.04	17.98
<b>Esophagus</b>	10	1	0.000610	0.000061	0.04	2.44
<b>Skin</b>	5	16,17, 14,15	0.001958	0.000098	0.01	0.98
<b>Bone Surface</b>	16.5		0.007745	0.001278	0.01	12.78
Mandible	1.3	7,8,10,11	0.005063	0.000066		
Calvarium	11.8	22,23,24	0.000222	0.000026		
Cervical spine	3.4	9	0.002460	0.000084		
<b>Salivary Glands</b>	100		0.006520	0.006520	0.01	65.20
Parotid	100	12,13	0.002660	0.002660		
Submandibular	100	5,6	0.002660	0.002660		
Sublingual	100	4	0.001200	0.001200		
<b>Brain</b>	100	20,21	0.000370	0.000370	0.01	3.70
<b>Remainder</b>			0.005935	0.000503	0.12	60.38
Lymphatic nodes	5	1, 3-13	0.002968	0.000148		
Muscle	5	1, 3-13	0.002968	0.000148		
Extrathoracic airway	100	18,19, 1, 3-13	0.002679	0.002679		
Oral mucosa	100	4-8,10-13	0.003566	0.003566		
<b>Pituitary</b>	100	20	0.000376	0.000376		
<b>Eyes</b>	100	16-19	0.000859	0.000859		
				<b>Effective dose</b>		<b>316.80</b>

Table A.7. Accuitomo full scan 4 x 4 cm<sup>2</sup>.

Dosimeter		Voltage (mV)	Dose (Gy)	Tissue
1	#1-1:	2.91	6.35E-04	Esophagus
2	#1-2:	0.94	2.38E-04	Left thyroid surface
3	#1-3:	0.76	1.87E-04	Midline thyroid
4	#1-4:	7.7	0.00171	Center sublingual gland
5	#1-5:	26.22	0.00611	Left submandibular gland
6	#2-1:	24.21	0.00476	Right submandibular gland
7	#2-2:	8.01	0.00173	Left mandible body
8	#2-3:	6.9	0.00145	Right mandible body
9	#2-4:	2.55	6.18E-04	Center cervical spine
10	#2-5:	1.86	4.58E-04	Left ramus
11	#3-1:	2.17	4.46E-04	Right ramus
12	#3-2:	3.29	7.33E-04	Left parotid
13	#3-3:	7.31	0.00159	Right parotid
14	#3-4:	1.29	3.25E-04	Left back of neck
15	#3-5:	2.01	4.95E-04	Right cheek
16	#4-1:	1.55	3.54E-04	Left lens of eye
17	#4-2:	0.98	2.30E-04	Right lens of eye
18	#4-3:	1.39	2.91E-04	Left orbit
19	#4-4:	1.06	2.50E-04	Right orbit
20	#4-5:	0.82	1.84E-04	Pituitary
21	#5-1:	0.55	1.46E-04	Midbrain
22	#5-2:	0.72	1.74E-04	Anterior calvarium
23	#5-3:	0.3	7.40E-05	Left calvarium
24	#5-4:	0.08	2.29E-05	Right calvarium
25	#5-5:	0.26	5.89E-05	Posterior calvarium

Table A.8. Accuitomo full scan 4 x 4 cm<sup>2</sup>.

Major Organ and Tissue	Irradiation Fraction	Dosimeter	Sums	H <sub>T</sub> ( $\mu$ Sv)	W <sub>T</sub>	ED ( $\mu$ Sv)
<b>Bone marrow</b>	16.5		0.001729	0.000285	0.12	34.24
Mandible	1.3	7,8,10,11	0.001021	0.000013		
Calvarium	11.8	22,23,24	0.000090	0.000011		
Cervical spine	3.4	9	0.000618	0.000021		
<b>Thyroid</b>	100	2,3	0.000213	0.000213	0.04	8.50
<b>Esophagus</b>	10	1	0.000635	0.000064	0.04	2.54
<b>Skin</b>	5	16,17, 14,15	0.000351	0.000018	0.01	0.18
<b>Bone Surface</b>	16.5		0.001729	0.000285	0.01	2.85
Mandible	1.3	7,8,10,11	0.001021	0.000013		
Calvarium	11.8	22,23,24	0.000090	0.000011		
Cervical spine	3.4	9	0.000618	0.000021		
<b>Salivary Glands</b>	100		0.008307	0.008307	0.01	83.07
Parotid	100	12,13	0.001162	0.001162		
Submandibular	100	5,6	0.005435	0.005435		
Sublingual	100	4	0.001710	0.001710		
<b>Brain</b>	100	20,21	0.000165	0.000165	0.01	1.65
<b>Remainder</b>			0.003405	0.000291	0.12	34.87
Lymphatic nodes	5	1, 3-13	0.001702	0.000085		
Muscle	5	1, 3-13	0.001702	0.000085		
Extrathoracic airway	100	18,19, 1, 3-13	0.001498	0.001498		
Oral mucosa	100	4-8,10-13	0.002110	0.002110		
<b>Pituitary</b>	100	20	0.000184	0.000184		
<b>Eyes</b>	100	16-19	0.000281	0.000281		
				<b>Effective dose</b>		<b>167.89</b>

Table A.9. Accuitomo 50 preview scans 4 x 4 cm<sup>2</sup>.

Dosimeter		Voltage (mV)	Dose (Gy)	Tissue
1	#1-1:	4.12	9.01E-04	Esophagus
2	#1-2:	1.97	0.0005	Left thyroid surface
3	#1-3:	0.73	1.78E-04	Midline thyroid
4	#1-4:	11.79	0.00262	Center sublingual gland
5	#1-5:	4.02	9.35E-04	Left submandibular gland
6	#2-1:	54.09	0.0106	Right submandibular gland
7	#2-2:	9.69	0.00209	Left mandible body
8	#2-3:	7.63	0.0016	Right mandible body
9	#2-4:	36.95	0.00895	Center cervical spine
10	#2-5:	1.33	3.26E-04	Left ramus
11	#3-1:	2.2	4.52E-04	Right ramus
12	#3-2:	10.94	0.00244	Left parotid
13	#3-3:	8.3	0.0018	Right parotid
14	#3-4:	78.14	0.0198	Left back of neck
15	#3-5:	3.05	7.50E-04	Right cheek
16	#4-1:	0.64	1.47E-04	Left lens of eye
17	#4-2:	1.52	3.58E-04	Right lens of eye
18	#4-3:	0.73	1.53E-04	Left orbit
19	#4-4:	1.51	3.57E-04	Right orbit
20	#4-5:	0.4	8.98E-05	Pituitary
21	#5-1:	0	0	Midbrain
22	#5-2:	0	0	Anterior calvarium
23	#5-3:	0	0	Left calvarium
24	#5-4:	0	0	Right calvarium
25	#5-5:	0	0	Posterior calvarium

Table A.10. Accuitomo 50 preview scans 4 x 4 cm<sup>2</sup>.

Major Organ and Tissue	Irradiation Fraction	Dosimeter	Sums	H <sub>T</sub> ( $\mu$ Sv)	W <sub>T</sub>	ED ( $\mu$ Sv)
<b>Bone marrow</b>	16.5		0.010067	0.001661	0.12	199.33
Mandible	1.3	7,8,10,11	0.001117	0.000015		
Calvarium	11.8	22,23,24	0.000000	0.000000		
Cervical spine	3.4	9	0.008950	0.000304		
<b>Thyroid</b>	100	2,3	0.000339	0.000339	0.04	13.56
<b>Esophagus</b>	10	1	0.000901	0.000090	0.04	3.60
<b>Skin</b>	5	16,17, 14,15	0.005264	0.000263	0.01	2.63
<b>Bone Surface</b>	16.5		0.010067	0.001661	0.01	16.61
Mandible	1.3	7,8,10,11	0.001117	0.000015		
Calvarium	11.8	22,23,24	0.000000	0.000000		
Cervical spine	3.4	9	0.008950	0.000304		
<b>Salivary Glands</b>	100		0.010508	0.010508	0.01	105.08
Parotid	100	12,13	0.002120	0.002120		
Submandibular	100	5,6	0.005768	0.005768		
Sublingual	100	4	0.002620	0.002620		
<b>Brain</b>	100	20,21	0.000045	0.000045	0.01	0.45
<b>Remainder</b>			0.005482	0.000400	0.12	48.00
Lymphatic nodes	5	1, 3-13	0.002741	0.000137		
Muscle	5	1, 3-13	0.002741	0.000137		
Extrathoracic airway	100	18,19, 1, 3-13	0.002386	0.002386		
Oral mucosa	100	4-8,10-13	0.002540	0.002540		
<b>Pituitary</b>	100	20	0.000090	0.000090		
<b>Eyes</b>	100	16-19	0.000254	0.000254		
				<b>Effective dose</b>		<b>389.26</b>

Table A.11. Accuitomo 50 preview scans 4 x 4 cm<sup>2</sup> (repeat).

Dosimeter		Voltage (mV)	Dose (Gy)	Tissue
1	#1-1:	3.7	8.09E-04	Esophagus
2	#1-2:	2.29	5.80E-04	Left thyroid surface
3	#1-3:	1.36	3.32E-04	Midline thyroid
4	#1-4:	11.35	0.00252	Center sublingual gland
5	#1-5:	5.26	0.00122	Left submandibular gland
6	#2-1:	57.67	0.0113	Right submandibular gland
7	#2-2:	12.87	0.00278	Left mandible body
8	#2-3:	7.38	0.00155	Right mandible body
9	#2-4:	34.02	0.00824	Center cervical spine
10	#2-5:	1.4	3.43E-04	Left ramus
11	#3-1:	2.04	4.19E-04	Right ramus
12	#3-2:	10.98	0.00245	Left parotid
13	#3-3:	6.54	0.00142	Right parotid
14	#3-4:	6.98	0.00176	Left back of neck
15	#3-5:	4.2	0.00103	Right cheek
16	#4-1:	0.12	2.85E-05	Left lens of eye
17	#4-2:	0.38	9.00E-05	Right lens of eye
18	#4-3:	0.2	4.15E-05	Left orbit
19	#4-4:	0.98	2.31E-04	Right orbit
20	#4-5:	0.07	1.62E-05	Pituitary
21	#5-1:	0	0	Midbrain
22	#5-2:	0	0	Anterior calvarium
23	#5-3:	0	0	Left calvarium
24	#5-4:	0	0	Right calvarium
25	#5-5:	0	0	Posterior calvarium

Table A.12. Accuitomo 50 preview scans 4 x 4 cm<sup>2</sup> (repeat).

Major Organ and Tissue	Irradiation Fraction	Dosimeter	Sums	H <sub>T</sub> (μSv)	W <sub>T</sub>	ED (μSv)
<b>Bone marrow</b>	16.5		0.009513	0.001570	0.12	188.36
Mandible	1.3	7,8,10,11	0.001273	0.000017		
Calvarium	11.8	22,23,24	0.000000	0.000000		
Cervical spine	3.4	9	0.008240	0.000280		
<b>Thyroid</b>	100	2,3	0.000456	0.000456	0.04	18.24
<b>Esophagus</b>	10	1	0.000809	0.000081	0.04	3.24
<b>Skin</b>	5	16,17, 14,15	0.000727	0.000036	0.01	0.36
<b>Bone Surface</b>	16.5		0.009513	0.001570	0.01	15.70
Mandible	1.3	7,8,10,11	0.001273	0.000017		
Calvarium	11.8	22,23,24	0.000000	0.000000		
Cervical spine	3.4	9	0.008240	0.000280		
<b>Salivary Glands</b>	100		0.010715	0.010715	0.01	107.15
Parotid	100	12,13	0.001935	0.001935		
Submandibular	100	5,6	0.006260	0.006260		
Sublingual	100	4	0.002520	0.002520		
<b>Brain</b>	100	20,21	0.000008	0.000008	0.01	0.08
<b>Remainder</b>			0.005564	0.000411	0.12	49.38
Lymphatic nodes	5	1, 3-13	0.002782	0.000139		
Muscle	5	1, 3-13	0.002782	0.000139		
Extrathoracic airway	100	18,19, 1, 3-13	0.002404	0.002404		
Oral mucosa	100	4-8,10-13	0.002667	0.002667		
<b>Pituitary</b>	100	20	0.000016	0.000016		
<b>Eyes</b>	100	16-19	0.000098	0.000098		
				<b>Effective dose</b>		<b>382.50</b>

Table A.13. Planmeca full scan 23 x 16 cm<sup>2</sup>.

Dosimeter		Voltage (mV)	Dose (Gy)	Tissue
1	#1-1:	16.23	0.00355	Esophagus
2	#1-2:	12.22	0.0031	Left thyroid surface
3	#1-3:	7.91	0.00194	Midline thyroid
4	#1-4:	19.55	0.00435	Center sublingual gland
5	#1-5:	13.23	0.00308	Left submandibular gland
6	#2-1:	18.67	0.00367	Right submandibular gland
7	#2-2:	19.93	0.0043	Left mandible body
8	#2-3:	16.85	0.00355	Right mandible body
9	#2-4:	17.3	0.00419	Center cervical spine
10	#2-5:	17	0.00418	Left ramus
11	#3-1:	19.19	0.00394	Right ramus
12	#3-2:	14.68	0.00328	Left parotid
13	#3-3:	14.68	0.00319	Right parotid
14	#3-4:	18.8	0.00475	Left back of neck
15	#3-5:	15.09	0.00371	Right cheek
16	#4-1:	17.39	0.00397	Left lens of eye
17	#4-2:	12.76	0.003	Right lens of eye
18	#4-3:	15.21	0.00319	Left orbit
19	#4-4:	13.53	0.00319	Right orbit
20	#4-5:	12.7	0.00284	Pituitary
21	#5-1:	7.63	0.00201	Midbrain
22	#5-2:	4.89	0.00119	Anterior calvarium
23	#5-3:	6.31	0.00157	Left calvarium
24	#5-4:	5.22	0.00148	Right calvarium
25	#5-5:	2.41	5.38E-04	Posterior calvarium

Table A.14. Planmeca full scan 23 x 16 cm<sup>2</sup>.

Major Organ and Tissue	Irradiation Fraction	Dosimeter	Sums	H <sub>T</sub> ( $\mu$ Sv)	W <sub>T</sub>	ED ( $\mu$ Sv)
<b>Bone marrow</b>	16.5		0.009596	0.001583	0.12	190.00
Mandible	1.3	7,8,10,11	0.003993	0.000052		
Calvarium	11.8	22,23,24	0.001413	0.000167		
Cervical spine	3.4	9	0.004190	0.000142		
<b>Thyroid</b>	100	2,3	0.002520	0.002520	0.04	100.80
<b>Esophagus</b>	10	1	0.003550	0.000355	0.04	14.20
<b>Skin</b>	5	16,17, 14,15	0.003858	0.000193	0.01	1.93
<b>Bone Surface</b>	16.5		0.009596	0.001583	0.01	15.83
Mandible	1.3	7,8,10,11	0.003993	0.000052		
Calvarium	11.8	22,23,24	0.001413	0.000167		
Cervical spine	3.4	9	0.004190	0.000142		
<b>Salivary Glands</b>	100		0.010960	0.010960	0.01	109.60
Parotid	100	12,13	0.003235	0.003235		
Submandibular	100	5,6	0.003375	0.003375		
Sublingual	100	4	0.004350	0.004350		
<b>Brain</b>	100	20,21	0.002425	0.002425	0.01	24.25
<b>Remainder</b>			0.007203	0.000587	0.12	70.43
Lymphatic nodes	5	1, 3-13	0.003602	0.000180		
Muscle	5	1, 3-13	0.003602	0.000180		
Extrathoracic airway	100	18,19, 1, 3-13	0.003543	0.003543		
Oral mucosa	100	4-8,10-13	0.003727	0.003727		
<b>Pituitary</b>	100	20	0.002840	0.002840		
<b>Eyes</b>	100	16-19	0.003338	0.003338		
				<b>Effective dose</b>		<b>527.04</b>

Table A.15. Planmeca 50 preview scans 23 x 16 cm<sup>2</sup>.

Dosimeter		Voltage (mV)	Dose (Gy)	Tissue
1	#1-1:	3.18	6.95E-04	Esophagus
2	#1-2:	2.19	5.55E-04	Left thyroid surface
3	#1-3:	0	0	Midline thyroid
4	#1-4:	5.46	0.00121	Center sublingual gland
5	#1-5:	0.51	1.19E-04	Left submandibular gland
6	#2-1:	4.75	9.33E-04	Right submandibular gland
7	#2-2:	3.28	7.07E-04	Left mandible body
8	#2-3:	0	0	Right mandible body
9	#2-4:	1.16	2.80E-04	Center cervical spine
10	#2-5:	2.54	6.25E-04	Left ramus
11	#3-1:	0	0	Right ramus
12	#3-2:	2.55	5.69E-04	Left parotid
13	#3-3:	2.24	4.86E-04	Right parotid
14	#3-4:	1.45	3.67E-04	Left back of neck
15	#3-5:	5.25	0.00129	Right cheek
16	#4-1:	0.33	7.55E-05	Left lens of eye
17	#4-2:	4.18	9.83E-04	Right lens of eye
18	#4-3:	1.98	4.15E-04	Left orbit
19	#4-4:	3.47	8.17E-04	Right orbit
20	#4-5:	2.19	4.88E-04	Pituitary
21	#5-1:	0.96	2.53E-04	Midbrain
22	#5-2:	1.04	2.52E-04	Anterior calvarium
23	#5-3:	0.96	2.39E-04	Left calvarium
24	#5-4:	0.3	8.58E-05	Right calvarium
25	#5-5:	0	0	Posterior calvarium

Table A.16. Planmeca 50 preview scans 23 x 16 cm<sup>2</sup>.

Major Organ and Tissue	Irradiation Fraction	Dosimeter	Sums	H <sub>T</sub> ( $\mu$ Sv)	W <sub>T</sub>	ED ( $\mu$ Sv)
<b>Bone marrow</b>	16.5		0.000805	0.000133	0.12	15.94
Mandible	1.3	7,8,10,11	0.000333	0.000004		
Calvarium	11.8	22,23,24	0.000192	0.000023		
Cervical spine	3.4	9	0.000280	0.000010		
<b>Thyroid</b>	100	2,3	0.000278	0.000278	0.04	11.10
<b>Esophagus</b>	10	1	0.000695	0.000070	0.04	2.78
<b>Skin</b>	5	16,17, 14,15	0.000679	0.000034	0.01	0.34
<b>Bone Surface</b>	16.5		0.000805	0.000133	0.01	1.33
Mandible	1.3	7,8,10,11	0.000333	0.000004		
Calvarium	11.8	22,23,24	0.000192	0.000023		
Cervical spine	3.4	9	0.000280	0.000010		
<b>Salivary Glands</b>	100		0.002264	0.002264	0.01	22.64
Parotid	100	12,13	0.000528	0.000528		
Submandibular	100	5,6	0.000526	0.000526		
Sublingual	100	4	0.001210	0.001210		
<b>Brain</b>	100	20,21	0.000371	0.000371	0.01	3.71
<b>Remainder</b>			0.000937	0.000081	0.12	9.72
Lymphatic nodes	5	1, 3-13	0.000469	0.000023		
Muscle	5	1, 3-13	0.000469	0.000023		
Extrathoracic airway	100	18,19, 1, 3-13	0.000490	0.000490		
Oral mucosa	100	4-8,10-13	0.000517	0.000517		
<b>Pituitary</b>	100	20	0.000488	0.000488		
<b>Eyes</b>	100	16-19	0.000573	0.000573		
				<b>Effective dose</b>		<b>67.55</b>

Table A.17. Carestream full scan 17 x 13.5 cm<sup>2</sup>.

Dosimeter		Voltage (mV)	Dose (Gy)	Tissue
1	#1-1:	15.57	0.0034	Esophagus
2	#1-2:	9.91	0.00251	Left thyroid surface
3	#1-3:	10.11	0.00247	Midline thyroid
4	#1-4:	18.13	0.00403	Center sublingual gland
5	#1-5:	19.56	0.00455	Left submandibular gland
6	#2-1:	17.2	0.00338	Right submandibular gland
7	#2-2:	17.3	0.00373	Left mandible body
8	#2-3:	19.33	0.00407	Right mandible body
9	#2-4:	16.97	0.00411	Center cervical spine
10	#2-5:	16.98	0.00418	Left ramus
11	#3-1:	19.26	0.00396	Right ramus
12	#3-2:	15.43	0.00344	Left parotid
13	#3-3:	14.05	0.00305	Right parotid
14	#3-4:	12.99	0.00328	Left back of neck
15	#3-5:	20.11	0.00495	Right cheek
16	#4-1:	12.35	0.00282	Left lens of eye
17	#4-2:	11.23	0.00264	Right lens of eye
18	#4-3:	17.55	0.00368	Left orbit
19	#4-4:	13.37	0.00315	Right orbit
20	#4-5:	5.38	0.0012	Pituitary
21	#5-1:	2.84	7.49E-04	Midbrain
22	#5-2:	2.29	5.56E-04	Anterior calvarium
23	#5-3:	2.28	5.65E-04	Left calvarium
24	#5-4:	2.16	6.11E-04	Right calvarium
25	#5-5:	1.05	2.34E-04	Posterior calvarium

Table A.18. Carestream full scan 17 x 13.5 cm<sup>2</sup>.

Major Organ and Tissue	Irradiation Fraction	Dosimeter	Sums	H <sub>T</sub> ( $\mu$ Sv)	W <sub>T</sub>	ED ( $\mu$ Sv)
<b>Bone marrow</b>	16.5		0.008672	0.001431	0.12	171.71
Mandible	1.3	7,8,10,11	0.003985	0.000052		
Calvarium	11.8	22,23,24	0.000577	0.000068		
Cervical spine	3.4	9	0.004110	0.000140		
<b>Thyroid</b>	100	2,3	0.002490	0.002490	0.04	99.60
<b>Esophagus</b>	10	1	0.003400	0.000340	0.04	13.60
<b>Skin</b>	5	16,17, 14,15	0.003423	0.000171	0.01	1.71
<b>Bone Surface</b>	16.5		0.008672	0.001431	0.01	14.31
Mandible	1.3	7,8,10,11	0.003985	0.000052		
Calvarium	11.8	22,23,24	0.000577	0.000068		
Cervical spine	3.4	9	0.004110	0.000140		
<b>Salivary Glands</b>	100		0.011240	0.011240	0.01	112.40
Parotid	100	12,13	0.003245	0.003245		
Submandibular	100	5,6	0.003965	0.003965		
Sublingual	100	4	0.004030	0.004030		
<b>Brain</b>	100	20,21	0.000975	0.000975	0.01	9.75
<b>Remainder</b>			0.007395	0.000604	0.12	72.44
Lymphatic nodes	5	1, 3-13	0.003698	0.000185		
Muscle	5	1, 3-13	0.003698	0.000185		
Extrathoracic airway	100	18,19, 1, 3-13	0.003657	0.003657		
Oral mucosa	100	4-8,10-13	0.003821	0.003821		
<b>Pituitary</b>	100	20	0.001200	0.001200		
<b>Eyes</b>	100	16-19	0.003073	0.003073		
				<b>Effective dose</b>		<b>495.52</b>

Table A.19. Carestream 50 preview scans 17 x 13.5 cm<sup>2</sup>.

Dosimeter		Voltage (mV)	Dose (Gy)	Tissue
1	#1-1:	2.32	5.08E-04	Esophagus
2	#1-2:	0.46	1.18E-04	Left thyroid surface
3	#1-3:	0.16	3.99E-05	Midline thyroid
4	#1-4:	2.8	6.22E-04	Center sublingual gland
5	#1-5:	3.55	8.26E-04	Left submandibular gland
6	#2-1:	0.19	3.70E-05	Right submandibular gland
7	#2-2:	2.22	4.79E-04	Left mandible body
8	#2-3:	0.26	5.50E-05	Right mandible body
9	#2-4:	0.94	2.29E-04	Center cervical spine
10	#2-5:	1.47	3.63E-04	Left ramus
11	#3-1:	0.28	5.82E-05	Right ramus
12	#3-2:	2.63	5.87E-04	Left parotid
13	#3-3:	1.01	2.20E-04	Right parotid
14	#3-4:	0.76	1.92E-04	Left back of neck
15	#3-5:	0	0	Right cheek
16	#4-1:	4.03	9.20E-04	Left lens of eye
17	#4-2:	1.25	2.93E-04	Right lens of eye
18	#4-3:	2.58	5.41E-04	Left orbit
19	#4-4:	0.5	1.18E-04	Right orbit
20	#4-5:	0.49	1.09E-04	Pituitary
21	#5-1:	0.79	2.08E-04	Midbrain
22	#5-2:	0	0	Anterior calvarium
23	#5-3:	0.12	3.04E-05	Left calvarium
24	#5-4:	0.2	5.55E-05	Right calvarium
25	#5-5:	0.04	8.76E-06	Posterior calvarium

Table A.20. Carestream 50 preview scans 17 x 13.5 cm<sup>2</sup>.

Major Organ and Tissue	Irradiation Fraction	Dosimeter	Sums	H <sub>T</sub> ( $\mu$ Sv)	W <sub>T</sub>	ED ( $\mu$ Sv)
<b>Bone marrow</b>	16.5		0.000496	0.000082	0.12	9.83
Mandible	1.3	7,8,10,11	0.000239	0.000003		
Calvarium	11.8	22,23,24	0.000029	0.000003		
Cervical spine	3.4	9	0.000229	0.000008		
<b>Thyroid</b>	100	2,3	0.000079	0.000079	0.04	3.16
<b>Esophagus</b>	10	1	0.000508	0.000051	0.04	2.03
<b>Skin</b>	5	16,17, 14,15	0.000351	0.000018	0.01	0.18
<b>Bone Surface</b>	16.5		0.000496	0.000082	0.01	0.82
Mandible	1.3	7,8,10,11	0.000239	0.000003		
Calvarium	11.8	22,23,24	0.000029	0.000003		
Cervical spine	3.4	9	0.000229	0.000008		
<b>Salivary Glands</b>	100		0.001457	0.001457	0.01	14.57
Parotid	100	12,13	0.000404	0.000404		
Submandibular	100	5,6	0.000432	0.000432		
Sublingual	100	4	0.000622	0.000622		
<b>Brain</b>	100	20,21	0.000159	0.000159	0.01	1.59
<b>Remainder</b>			0.000671	0.000056	0.12	6.73
Lymphatic nodes	5	1, 3-13	0.000335	0.000017		
Muscle	5	1, 3-13	0.000335	0.000017		
Extrathoracic airway	100	18,19, 1, 3-13	0.000335	0.000335		
Oral mucosa	100	4-8,10-13	0.000361	0.000361		
<b>Pituitary</b>	100	20	0.000109	0.000109		
<b>Eyes</b>	100	16-19	0.000468	0.000468		
				<b>Effective dose</b>		<b>38.90</b>

Table A.21. i-CAT full scan 23 x 17 cm<sup>2</sup>.

Dosimeter		Voltage (mV)	Dose (Gy)	Tissue
1	#1-1:	7.94	0.00174	Esophagus
2	#1-2:	6.71	0.0017	Left thyroid surface
3	#1-3:	4.4	0.00108	Midline thyroid
4	#1-4:	9.93	0.00221	Center sublingual gland
5	#1-5:	5.16	0.0012	Left submandibular gland
6	#2-1:	5.63	0.00111	Right submandibular gland
7	#2-2:	6.86	0.00148	Left mandible body
8	#2-3:	8.32	0.00175	Right mandible body
9	#2-4:	7.14	0.00173	Center cervical spine
10	#2-5:	6.42	0.00158	Left ramus
11	#3-1:	5.73	0.00118	Right ramus
12	#3-2:	4.3	9.60E-04	Left parotid
13	#3-3:	5.29	0.00115	Right parotid
14	#3-4:	4.35	0.0011	Left back of neck
15	#3-5:	4.94	0.00121	Right cheek
16	#4-1:	5.91	0.00135	Left lens of eye
17	#4-2:	4.87	0.00114	Right lens of eye
18	#4-3:	4.77	9.99E-04	Left orbit
19	#4-4:	6.27	0.00148	Right orbit
20	#4-5:	6.6	0.00147	Pituitary
21	#5-1:	2.08	5.48E-04	Midbrain
22	#5-2:	2.13	5.17E-04	Anterior calvarium
23	#5-3:	1.95	4.84E-04	Left calvarium
24	#5-4:	2.87	8.10E-04	Right calvarium
25	#5-5:	0.77	1.72E-04	Posterior calvarium

Table A.22. i-CAT full scan 23 x 17 cm<sup>2</sup>.

Major Organ and Tissue	Irradiation Fraction	Dosimeter	Sums	H <sub>T</sub> ( $\mu$ Sv)	W <sub>T</sub>	ED ( $\mu$ Sv)
<b>Bone marrow</b>	16.5		0.003831	0.000632	0.12	75.86
Mandible	1.3	7,8,10,11	0.001498	0.000019		
Calvarium	11.8	22,23,24	0.000604	0.000071		
Cervical spine	3.4	9	0.001730	0.000059		
<b>Thyroid</b>	100	2,3	0.001390	0.001390	0.04	55.60
<b>Esophagus</b>	10	1	0.001740	0.000174	0.04	6.96
<b>Skin</b>	5	16,17, 14,15	0.001200	0.000060	0.01	0.60
<b>Bone Surface</b>	16.5		0.003831	0.000632	0.01	6.32
Mandible	1.3	7,8,10,11	0.001498	0.000019		
Calvarium	11.8	22,23,24	0.000604	0.000071		
Cervical spine	3.4	9	0.001730	0.000059		
<b>Salivary Glands</b>	100		0.004420	0.004420	0.01	44.20
Parotid	100	12,13	0.001055	0.001055		
Submandibular	100	5,6	0.001155	0.001155		
Sublingual	100	4	0.002210	0.002210		
<b>Brain</b>	100	20,21	0.001009	0.001009	0.01	10.09
<b>Remainder</b>			0.002862	0.000227	0.12	27.22
Lymphatic nodes	5	1, 3-13	0.001431	0.000072		
Muscle	5	1, 3-13	0.001431	0.000072		
Extrathoracic airway	100	18,19, 1, 3-13	0.001404	0.001404		
Oral mucosa	100	4-8,10-13	0.001402	0.001402		
<b>Pituitary</b>	100	20	0.001470	0.001470		
<b>Eyes</b>	100	16-19	0.001242	0.001242		
<b>Effective dose</b>						<b>226.85</b>

Table A.23. i-CAT 50 preview scans 23 x 17 cm<sup>2</sup>.

Dosimeter		Voltage (mV)	Dose (Gy)	Tissue
1	#1-1:	6.52	0.00142	Esophagus
2	#1-2:	0.54	1.36E-04	Left thyroid surface
3	#1-3:	0.14	3.47E-05	Midline thyroid
4	#1-4:	11.14	0.00248	Center sublingual gland
5	#1-5:	2.19	5.10E-04	Left submandibular gland
6	#2-1:	8.38	0.00165	Right submandibular gland
7	#2-2:	0.14	3.02E-05	Left mandible body
8	#2-3:	0.43	8.95E-05	Right mandible body
9	#2-4:	0.4	9.61E-05	Center cervical spine
10	#2-5:	0.63	1.55E-04	Left ramus
11	#3-1:	0	0	Right ramus
12	#3-2:	3.61	8.05E-04	Left parotid
13	#3-3:	8.59	0.00187	Right parotid
14	#3-4:	0	0	Left back of neck
15	#3-5:	7.2	0.00177	Right cheek
16	#4-1:	0.85	1.94E-04	Left lens of eye
17	#4-2:	4.02	9.45E-04	Right lens of eye
18	#4-3:	2.57	5.38E-04	Left orbit
19	#4-4:	7.89	0.00186	Right orbit
20	#4-5:	3.34	7.45E-04	Pituitary
21	#5-1:	0.61	1.60E-04	Midbrain
22	#5-2:	1.91	4.65E-04	Anterior calvarium
23	#5-3:	2.75	6.82E-04	Left calvarium
24	#5-4:	1.97	5.56E-04	Right calvarium
25	#5-5:	0	0	Posterior calvarium

Table A.24. i-CAT 50 previews 23 x 17 cm<sup>2</sup>.

Major Organ and Tissue	Irradiation Fraction	Dosimeter	Sums	H <sub>T</sub> ( $\mu$ Sv)	W <sub>T</sub>	ED ( $\mu$ Sv)
<b>Bone marrow</b>	16.5		0.000732	0.000121	0.12	14.50
Mandible	1.3	7,8,10,11	0.000069	0.000001		
Calvarium	11.8	22,23,24	0.000568	0.000067		
Cervical spine	3.4	9	0.000096	0.000003		
<b>Thyroid</b>	100	2,3	0.000085	0.000085	0.04	3.41
<b>Esophagus</b>	10	1	0.001420	0.000142	0.04	5.68
<b>Skin</b>	5	16,17, 14,15	0.000727	0.000036	0.01	0.36
<b>Bone Surface</b>	16.5		0.000732	0.000121	0.01	1.21
Mandible	1.3	7,8,10,11	0.000069	0.000001		
Calvarium	11.8	22,23,24	0.000568	0.000067		
Cervical spine	3.4	9	0.000096	0.000003		
<b>Salivary Glands</b>	100		0.004898	0.004898	0.01	48.98
Parotid	100	12,13	0.001338	0.001338		
Submandibular	100	5,6	0.001080	0.001080		
Sublingual	100	4	0.002480	0.002480		
<b>Brain</b>	100	20,21	0.000453	0.000453	0.01	4.53
<b>Remainder</b>			0.001523	0.000134	0.12	16.10
Lymphatic nodes	5	1, 3-13	0.000762	0.000038		
Muscle	5	1, 3-13	0.000762	0.000038		
Extrathoracic airway	100	18,19, 1, 3-13	0.000824	0.000824		
Oral mucosa	100	4-8,10-13	0.000843	0.000843		
<b>Pituitary</b>	100	20	0.000745	0.000745		
<b>Eyes</b>	100	16-19	0.000884	0.000884		
				<b>Effective dose</b>		<b>94.76</b>

Table A.25. i-CAT FLX full scan 23 x 17 cm<sup>2</sup>.

Dosimeter		Voltage (mV)	Dose (cGy)	Tissue
1	#1-1:	12.53	0.255975	Esophagus
2	#1-2:	10.34	0.201128	Left thyroid surface
3	#1-3:	8.98	0.178778	Midline thyroid
4	#1-4:	9.96	0.193699	Center sublingual gland
5	#1-5:	8.64	0.171157	Left submandibular gland
6	#2-1:	8.09	0.157087	Right submandibular gland
7	#2-2:	7.31	0.144153	Left mandible body
8	#2-3:	8.57	0.162157	Right mandible body
9	#2-4:	8.11	0.158491	Center cervical spine
10	#2-5:	7.49	0.147644	Left ramus
11	#3-1:	5.65	0.109624	Right ramus
12	#3-2:	5.95	0.118337	Left parotid
13	#3-3:	8.28	0.158834	Right parotid
14	#3-4:	9	0.181014	Left back of neck
15	#3-5:	6.38	0.125813	Right cheek
16	#4-1:	6.78	0.131421	Left lens of eye
17	#4-2:	6.71	0.129938	Right lens of eye
18	#4-3:	5.82	0.113362	Left orbit
19	#4-4:	7.14	0.136729	Right orbit
20	#4-5:	4.9	0.091537	Pituitary
21	#5-1:	2.11	0.040476	Midbrain
22	#5-2:	2.2	0.043912	Anterior calvarium
23	#5-3:	2.2	0.041905	Left calvarium
24	#5-4:	0.97	0.019553	Right calvarium
25	#5-5:	1.18	0.022502	Posterior calvarium

Table A.26. i-CAT FLX full scan 23 x 17 cm<sup>2</sup>.

Major Organ and Tissue	Irradiation Fraction	Dosimeter	Sums	H <sub>T</sub> (μSv)	W <sub>T</sub>	ED (μSv)
<b>Bone marrow</b>	16.5		0.334509	0.055194	0.12	66.23
Mandible	1.3	7,8,10,11	0.140895	0.001832		
Calvarium	11.8	22,23,24	0.035123	0.004145		
Cervical spine	3.4	9	0.158491	0.005389		
<b>Thyroid</b>	100	2,3	0.189953	0.189953	0.04	75.98
<b>Esophagus</b>	10	1	0.255975	0.025598	0.04	10.24
<b>Skin</b>	5	16,17, 14,15	0.142046	0.007102	0.01	0.71
<b>Bone Surface</b>	16.5		0.334509	0.055194	0.01	5.52
Mandible	1.3	7,8,10,11	0.140895	0.001832		
Calvarium	11.8	22,23,24	0.035123	0.004145		
Cervical spine	3.4	9	0.158491	0.005389		
<b>Salivary Glands</b>	100		0.496407	0.496407	0.01	49.64
Parotid	100	12,13	0.138585	0.138585		
Submandibular	100	5,6	0.164122	0.164122		
Sublingual	100	4	0.193699	0.193699		
<b>Brain</b>	100	20,21	0.066007	0.066007	0.01	6.60
<b>Remainder</b>			0.325989	0.025022	0.12	30.03
Lymphatic nodes	5	1, 3-13	0.162995	0.008150		
Muscle	5	1, 3-13	0.162995	0.008150		
Extrathoracic airway	100	18,19, 1, 3-13	0.157573	0.157573		
Oral mucosa	100	4-8,10-13	0.151410	0.151410		
<b>Pituitary</b>	100	20	0.091537	0.091537		
<b>Eyes</b>	100	16-19	0.127862	0.127862		
				<b>Effective dose</b>		<b>244.95</b>

Table A.27. i-CAT FLX 50 previews 23 x 17 cm<sup>2</sup>.

Dosimeter		Voltage (mV)	Dose (cGy)	Tissue
1	#1-1:	10.24	0.209193	Esophagus
2	#1-2:	7.03	0.136744	Left thyroid surface
3	#1-3:	12.21	0.243082	Midline thyroid
4	#1-4:	13.94	0.271101	Center sublingual gland
5	#1-5:	6.9	0.136688	Left submandibular gland
6	#2-1:	9.45	0.183495	Right submandibular gland
7	#2-2:	3.51	0.069217	Left mandible body
8	#2-3:	8.21	0.155345	Right mandible body
9	#2-4:	1.45	0.028337	Center cervical spine
10	#2-5:	1.77	0.034891	Left ramus
11	#3-1:	16.92	0.328289	Right ramus
12	#3-2:	2.11	0.041965	Left parotid
13	#3-3:	13.89	0.266449	Right parotid
14	#3-4:	0	0	Left back of neck
15	#3-5:	16.22	0.319858	Right cheek
16	#4-1:	1.39	0.026943	Left lens of eye
17	#4-2:	5.02	0.097211	Right lens of eye
18	#4-3:	2.06	0.040125	Left orbit
19	#4-4:	8.02	0.153581	Right orbit
20	#4-5:	2.42	0.045208	Pituitary
21	#5-1:	1.04	0.01995	Midbrain
22	#5-2:	1.19	0.023752	Anterior calvarium
23	#5-3:	0.31	0.005905	Left calvarium
24	#5-4:	0.12	0.002419	Right calvarium
25	#5-5:	0.02	0.000381	Posterior calvarium

Table A.28. i-CAT FLX 50 previews 23 x 17 cm<sup>2</sup>.

Major Organ and Tissue	Irradiation Fraction	Dosimeter	Sums	H <sub>T</sub> (μSv)	W <sub>T</sub>	ED (μSv)
<b>Bone marrow</b>	16.5		0.185964	0.030684	0.12	36.82
Mandible	1.3	7,8,10,11	0.146935	0.001910		
Calvarium	11.8	22,23,24	0.010692	0.001262		
Cervical spine	3.4	9	0.028337	0.000963		
<b>Thyroid</b>	100	2,3	0.189913	0.189913	0.04	75.97
<b>Esophagus</b>	10	1	0.209193	0.020919	0.04	8.37
<b>Skin</b>	5	16,17, 14,15	0.111003	0.005550	0.01	0.56
<b>Bone Surface</b>	16.5		0.185964	0.030684	0.01	3.07
Mandible	1.3	7,8,10,11	0.146935	0.001910		
Calvarium	11.8	22,23,24	0.010692	0.001262		
Cervical spine	3.4	9	0.028337	0.000963		
<b>Salivary Glands</b>	100		0.585399	0.585399	0.01	58.54
Parotid	100	12,13	0.154207	0.154207		
Submandibular	100	5,6	0.160091	0.160091		
Sublingual	100	4	0.271101	0.271101		
<b>Brain</b>	100	20,21	0.032579	0.032579	0.01	3.26
<b>Remainder</b>			0.328009	0.025853	0.12	31.02
Lymphatic nodes	5	1, 3-13	0.164004	0.008200		
Muscle	5	1, 3-13	0.164004	0.008200		
Extrathoracic airway	100	18,19, 1, 3-13	0.154411	0.154411		
Oral mucosa	100	4-8,10-13	0.165271	0.165271		
<b>Pituitary</b>	100	20	0.045208	0.045208		
<b>Eyes</b>	100	16-19	0.079465	0.079465		
				<b>Effective dose</b>		<b>217.60</b>

Table A.29. i-CAT background scan 23 x 17 cm<sup>2</sup>.

Dosimeter		Voltage (mV)	Dose (Gy)	Tissue
1	#1-1:	0.38	8.41E-05	Esophagus
2	#1-2:	0.2	5.16E-05	Left thyroid surface
3	#1-3:	0.4	9.83E-05	Midline thyroid
4	#1-4:	0.51	1.13E-04	Center sublingual gland
5	#1-5:	0.08	1.87E-05	Left submandibular gland
6	#2-1:	0.14	2.79E-05	Right submandibular gland
7	#2-2:	0.62	1.35E-04	Left mandible body
8	#2-3:	0.64	1.34E-04	Right mandible body
9	#2-4:	0.44	1.06E-04	Center cervical spine
10	#2-5:	0.45	1.10E-04	Left ramus
11	#3-1:	0.7	1.44E-04	Right ramus
12	#3-2:	0.4	8.93E-05	Left parotid
13	#3-3:	0.38	8.18E-05	Right parotid
14	#3-4:	0.27	6.78E-05	Left back of neck
15	#3-5:	0.32	7.80E-05	Right cheek
16	#4-1:	0.77	1.76E-04	Left lens of eye
17	#4-2:	0.83	1.94E-04	Right lens of eye
18	#4-3:	0.62	1.30E-04	Left orbit
19	#4-4:	0.43	0.0001	Right orbit
20	#4-5:	0.64	1.44E-04	Pituitary
21	#5-1:	0	2.16E-07	Midbrain
22	#5-2:	0.45	1.10E-04	Anterior calvarium
23	#5-3:	0.16	3.97E-05	Left calvarium
24	#5-4:	0	0	Right calvarium
25	#5-5:	0.33	7.30E-05	Posterior calvarium

Table A.30. i-CAT background scan 23 x 17 cm<sup>2</sup>.

Major Organ and Tissue	Irradiation Fraction	Dosimeter	Sums	H <sub>T</sub> ( $\mu$ Sv)	W <sub>T</sub>	ED ( $\mu$ Sv)
<b>Bone marrow</b>	16.5		0.000287	0.000047	0.12	5.68
Mandible	1.3	7,8,10,11	0.000131	0.000002		
Calvarium	11.8	22,23,24	0.000050	0.000006		
Cervical spine	3.4	9	0.000106	0.000004		
<b>Thyroid</b>	100	2,3	0.000075	0.000075	0.04	3.00
<b>Esophagus</b>	10	1	0.000084	0.000008	0.04	0.34
<b>Skin</b>	5	16,17, 14,15	0.000129	0.000006	0.01	0.06
<b>Bone Surface</b>	16.5		0.000287	0.000047	0.01	0.47
Mandible	1.3	7,8,10,11	0.000131	0.000002		
Calvarium	11.8	22,23,24	0.000050	0.000006		
Cervical spine	3.4	9	0.000106	0.000004		
<b>Salivary Glands</b>	100		0.000222	0.000222	0.01	2.22
Parotid	100	12,13	0.000086	0.000086		
Submandibular	100	5,6	0.000023	0.000023		
Sublingual	100	4	0.000113	0.000113		
<b>Brain</b>	100	20,21	0.000072	0.000072	0.01	0.72
<b>Remainder</b>			0.000190	0.000016	0.12	1.87
Lymphatic nodes	5	1, 3-13	0.000095	0.000005		
Muscle	5	1, 3-13	0.000095	0.000005		
Extrathoracic airway	100	18,19, 1, 3-13	0.000098	0.000098		
Oral mucosa	100	4-8,10-13	0.000095	0.000095		
<b>Pituitary</b>	100	20	0.000144	0.000144		
<b>Eyes</b>	100	16-19	0.000150	0.000150		
				<b>Effective dose</b>		<b>14.36</b>

Table A.31. Planmeca 5 panoramic radiographs.

Dosimeter		Voltage (mV)	Dose (Gy)	Tissue
1	#1-1:	4.97	0.00109	Esophagus
2	#1-2:	2.32	5.87E-04	Left thyroid surface
3	#1-3:	8.82	0.00216	Midline thyroid
4	#1-4:	14.79	0.00329	Center sublingual gland
5	#1-5:	7.72	0.0018	Left submandibular gland
6	#2-1:	9.06	0.00178	Right submandibular gland
7	#2-2:	3.91	8.44E-04	Left mandible body
8	#2-3:	3.79	7.97E-04	Right mandible body
9	#2-4:	8.29	0.00201	Center cervical spine
10	#2-5:	4.69	0.00115	Left ramus
11	#3-1:	7.23	0.00149	Right ramus
12	#3-2:	6.71	0.0015	Left parotid
13	#3-3:	9.96	0.00216	Right parotid
14	#3-4:	5.35	0.00135	Left back of neck
15	#3-5:	0.51	1.27E-04	Right cheek
16	#4-1:	0.43	9.76E-05	Left lens of eye
17	#4-2:	0.73	1.73E-04	Right lens of eye
18	#4-3:	1.41	2.96E-04	Left orbit
19	#4-4:	1.12	2.65E-04	Right orbit
20	#4-5:	1.47	3.28E-04	Pituitary
21	#5-1:	0.54	1.41E-04	Midbrain
22	#5-2:	0.35	8.39E-05	Anterior calvarium
23	#5-3:	0.3	7.47E-05	Left calvarium
24	#5-4:	0.28	8.04E-05	Right calvarium
25	#5-5:	0.32	7.11E-05	Posterior calvarium

Table A.32. Planmeca 5 panoramic radiographs.

Major Organ and Tissue	Irradiation Fraction	Dosimeter	Sums	$H_T$ ( $\mu\text{Sv}$ )	$W_T$	ED ( $\mu\text{Sv}$ )
<b>Bone marrow</b>	16.5		0.003160	0.000521	0.12	62.57
Mandible	1.3	7,8,10,11	0.001070	0.000014		
Calvarium	11.8	22,23,24	0.000080	0.000009		
Cervical spine	3.4	9	0.002010	0.000068		
<b>Thyroid</b>	100	2,3	0.001374	0.001374	0.04	54.94
<b>Esophagus</b>	10	1	0.001090	0.000109	0.04	4.36
<b>Skin</b>	5	16,17, 14,15	0.000437	0.000022	0.01	0.22
<b>Bone Surface</b>	16.5		0.003160	0.000521	0.01	5.21
Mandible	1.3	7,8,10,11	0.001070	0.000014		
Calvarium	11.8	22,23,24	0.000080	0.000009		
Cervical spine	3.4	9	0.002010	0.000068		
<b>Salivary Glands</b>	100		0.006910	0.006910	0.01	69.10
Parotid	100	12,13	0.001830	0.001830		
Submandibular	100	5,6	0.001790	0.001790		
Sublingual	100	4	0.003290	0.003290		
<b>Brain</b>	100	20,21	0.000235	0.000235	0.01	2.35
<b>Remainder</b>			0.003345	0.000253	0.12	30.34
Lymphatic nodes	5	1, 3-13	0.001673	0.000084		
Muscle	5	1, 3-13	0.001673	0.000084		
Extrathoracic airway	100	18,19, 1, 3-13	0.001474	0.001474		
Oral mucosa	100	4-8,10-13	0.001646	0.001646		
<b>Pituitary</b>	100	20	0.000328	0.000328		
<b>Eyes</b>	100	16-19	0.000208	0.000208		
<b>Effective dose</b>						<b>229.08</b>

Table A.33. Planmeca 50 lateral cephalometric radiographs.

Dosimeter		Voltage (mV)	Dose (Gy)	Tissue
1	#1-1:	3.18	6.96E-04	Esophagus
2	#1-2:	6.53	0.00166	Left thyroid surface
3	#1-3:	2.89	7.07E-04	Midline thyroid
4	#1-4:	3.28	7.28E-04	Center sublingual gland
5	#1-5:	6.13	0.00143	Left submandibular gland
6	#2-1:	0.94	1.84E-04	Right submandibular gland
7	#2-2:	2.66	5.73E-04	Left mandible body
8	#2-3:	0.33	6.99E-05	Right mandible body
9	#2-4:	1.59	3.86E-04	Center cervical spine
10	#2-5:	5.08	0.00125	Left ramus
11	#3-1:	0.27	5.47E-05	Right ramus
12	#3-2:	4.51	0.00101	Left parotid
13	#3-3:	0.72	1.56E-04	Right parotid
14	#3-4:	7.59	0.00192	Left back of neck
15	#3-5:	0.59	1.44E-04	Right cheek
16	#4-1:	5.08	0.00116	Left lens of eye
17	#4-2:	2.19	5.15E-04	Right lens of eye
18	#4-3:	3.48	7.28E-04	Left orbit
19	#4-4:	0.63	1.48E-04	Right orbit
20	#4-5:	1.52	3.39E-04	Pituitary
21	#5-1:	1.7	4.50E-04	Midbrain
22	#5-2:	0.42	1.03E-04	Anterior calvarium
23	#5-3:	2.56	6.35E-04	Left calvarium
24	#5-4:	0.44	1.26E-04	Right calvarium
25	#5-5:	1.2	2.68E-04	Posterior calvarium

Table A.34. Planmeca 50 lateral cephalometric radiographs.

Major Organ and Tissue	Irradiation Fraction	Dosimeter	Sums	$H_T$ ( $\mu\text{Sv}$ )	$W_T$	ED ( $\mu\text{Sv}$ )
<b>Bone marrow</b>	16.5		0.001161	0.000192	0.12	22.99
Mandible	1.3	7,8,10,11	0.000487	0.000006		
Calvarium	11.8	22,23,24	0.000288	0.000034		
Cervical spine	3.4	9	0.000386	0.000013		
<b>Thyroid</b>	100	2,3	0.001184	0.001184	0.04	47.34
<b>Esophagus</b>	10	1	0.000696	0.000070	0.04	2.78
<b>Skin</b>	5	16,17, 14,15	0.000935	0.000047	0.01	0.47
<b>Bone Surface</b>	16.5		0.001161	0.000192	0.01	1.92
Mandible	1.3	7,8,10,11	0.000487	0.000006		
Calvarium	11.8	22,23,24	0.000288	0.000034		
Cervical spine	3.4	9	0.000386	0.000013		
<b>Salivary Glands</b>	100		0.002118	0.002118	0.01	21.18
Parotid	100	12,13	0.000583	0.000583		
Submandibular	100	5,6	0.000807	0.000807		
Sublingual	100	4	0.000728	0.000728		
<b>Brain</b>	100	20,21	0.000395	0.000395	0.01	3.95
<b>Remainder</b>			0.001207	0.000096	0.12	11.51
Lymphatic nodes	5	1, 3-13	0.000604	0.000030		
Muscle	5	1, 3-13	0.000604	0.000030		
Extrathoracic airway	100	18,19, 1, 3-13	0.000580	0.000580		
Oral mucosa	100	4-8,10-13	0.000606	0.000606		
<b>Pituitary</b>	100	20	0.000339	0.000339		
<b>Eyes</b>	100	16-19	0.000638	0.000638		
<b>Effective dose</b>						<b>112.12</b>

## LITERATURE CITED

1. Lorenzoni DC, Bolognese AM, Garib DG, Guedes FR, Sant'Anna EF. Cone-beam computed tomography and radiographs in dentistry: Aspects related to radiation dose. *International Journal of Dentistry* 2012;2012:1-10.
2. Rottke D, Patzelt S, Poxleitner P, Schulze D. Effective dose span of ten different cone beam CT devices. *Dentomaxillofacial Radiology* 2013;42:1-5.
3. Koivisto J, PhLic T, Kiljunen T, Tapiovaara M, Wolff J, Kortesniemi M. Assessment of radiation exposure in dental cone-beam computerized tomography with the use of metal-oxide semiconductor field-effect transistor (MOSFET) dosimeters and monte carlo simulations. *Oral Surgery, Oral Medicine, Oral Pathology, and Oral Radiology* 2012;114(3):393-400.
4. Najjar AA, Colosi D, Dauer LT, Prins R, Patchell G, Branets I, Goren AD, Faber RD. Comparison of adult and child radiation equivalent doses from 2 dental cone-beam computed tomography units. *American Journal of Orthodontics and Dentofacial Orthopedics* 2013;143(6):784-792.
5. Qu XM, Li G, Sanderink GCH, Zhang ZY, Ma XC. Dose reduction of cone beam CT scanning for the entire oral and maxillofacial regions with thyroid collars. *Dentomaxillofacial Radiology* 2012;41:373-378.
6. Li G. Patient radiation dose and protection from cone-beam computed tomography. *Imaging Science in Dentistry* 2013; 43: 63-9.
7. Brisco J, Fuller K, Lee N, Andrew D. Cone beam computed tomography for imaging orbital trauma – image quality and radiation dose compared with conventional multislice computed tomography. *Journal of Oral and Maxillofacial Surgery* 2014;52:76-80.

8. Pauwels R, Theodorakou C, Walker A, Bosmans H, Jacobs R, Horner K, Bogaerts R. Dose distribution for dental cone beam CT and its implication for defining a dose index. *Dentomaxillofacial Radiology* 2012;41:583-593.
9. Bornstein MM, Scarfe WC, Vaughn V, Jacobs R. Cone Beam Computed Tomography in implant dentistry: A systematic review focusing on guidelines, indications, and radiation dose risks. *International Journal of Oral & Maxillofacial Implants* 2014;29:55-77.
10. Brooks SL. Radiation doses of common dental radiographic examinations: A review. *Acta Stomatologica Croatica* 2008;42(3):207-217.
11. Wrixon AD. New ICRP Recommendations. *Journal of Radiological Protection*. 2008;28:161-168.
12. The 2007 Recommendations of the International Commission on Radiological Protection. ICRP publication 103. *Annals of the ICRP* 2007;37(2-4):1-332.
13. Silva MAG, Wolf U, Heinicke F, Grundler K, Visser H, Hirsch E. Effective dosages for recording Veraviewepocs dental panoramic images: analog film, digital, and panoramic scout for CBCT. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology* 2008;106(4):571-577.
14. Ludlow JB, Walker C. Assessment of phantom dosimetry and image quality of i-CAT FLX cone-beam computed tomography. *American Journal of Orthodontics and Dentofacial Orthopedics* 2013;144(6):802-817.
15. Wang AS, Stayman JW, Otake Y, Vogt S, Kleinszig G, Khanna AJ, Gallia GL, Siewerdsen JH. Low-dose preview for patient-specific, task-specific technique selection in cone-beam CT. *Medical Physics* 2014;41(7):071915.
16. Derman P, Atwal P, Duzenli C, Thakur Y, Ford NL. Dose measurements for dental cone-beam CT: a comparison with MSCT and panoramic imaging. *Physics in Medicine and Biology* 2014;59(12):3201-22.

17. Ludlow JB. Comment on "Effective dose range for dental cone beam computed tomography scanners". *European Journal of Radiology* 2012;81(12):4219-20.
18. Carrafiello G, Dizonno M, Colli V, Strocchi S, Pozzi TS, Leonardi A, Giorgianni A, Barresi M, Macchi A, Bracchi E, Conte L, Fugazzola. Comparative study of jaws with multislice computed tomography and cone-beam computed tomography. *La Radiologica Medica* 2010;115(4):600-11.
19. Qi ZY, Deng XW, Huang SM, Shiu A, Lerch M, Metcalfe P, Rosenfeld A, Kron T. Real-time in vivo dosimetry with MOSFET detectors in serial tomotherapy for head and neck cancer patients. *International Journal of Radiation Oncology, Biology, and Physics* 2011;80(5):1581-8.
20. Koivisto J, Kiljunen T, Wolff J, Kortesniemi M. Characterization of MOSFET dosimeter angular dependence in three rotational axes measured free-in-air and in soft-tissue equivalent material. *Journal of Radiation Research* 2013;54(5):943-949.
21. Buzurovic I, Showalter TN, Studenski MT, Den RB, Dicker AP, Cao J, Xiao Y, Yu Y, Harrison A. Commissioning and implementation of an implantable dosimeter for radiation therapy. *Journal of Applied Clinical Medical Physics* 2013;14(2):3989.
22. Dawood A, Sauret-Jackson V, Patel S, Darwood A. A novel alignment device for cone beam computed tomography: principle and application. *Dentomaxillofacial Radiology* 2014;39(6):375-82.
23. Alquerban A, Jacobs R, van Keirsbilck P-J, Aly M, Swinnen S, Fieuws S, Willems G. The effect of using CBCT in the diagnosis of canine impaction and its impact on the orthodontic treatment outcome. *Journal of Orthodontic Science* 2014;3(2):34–40.
24. Nelson AP, Ding GX. An alternative approach to account for patient organ doses from imaging guidance procedures. *Radiotherapy and Oncology* 2014;112(1):112-118.

25. Razi T, Niknami M, Alavi Ghazani F. Relationship between Hounsfield Unit in CT Scan and Gray Scale in CBCT. *Journal of Dental Research, Dental Clinics, Dental Prospects* 2014;8(2):107-10.
26. Kim D, Rashsuren O, Kim E. Conversion coefficients for the estimation of effective dose in cone-beam CT. *Imaging Science in Dentistry* 2014;44(1):21-29.
27. Schieck JRK. Dosimetry of a Next Generation i-CAT CBCT machine as compared to a digital panoramic and lateral cephalogram in patient diagnosis and treatment at the University of Minnesota Division of Orthodontics. Master of Science Thesis; 2010.
28. White S, Pharoah M. Health physics. 5th ed. City: St. Louis, Missouri, Publisher Mosby; 2004:47-54.
29. Dixon RL, Boone JM. Cone beam CT dosimetry: A unified and self-consistent approach including all scan modalities-With or without phantom motion. *Medical Physics* 2010;37(6):2703-2718.
30. Qu XM, Li G, Ludlow JB, Zhang ZY, Ma XC. Effective radiation dose of ProMax 3D cone-beam computerized tomography scanner with different dental protocols. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology* 2010;110(6):770-6.
31. Cheung T, Butson MJ, Yu PK. Energy dependence corrections to MOSFET dosimetric sensitivity. *Australasian Physics and Engineering Sciences in Medicine* 2009;32(1):16-20.
32. Manninen AL, Kotiaho A, Nikkinen J, Nieminen MT. Validation of a MOSFET dosimeter system for determining the absorbed and effective radiation doses in diagnostic radiology. *Radiation Protection Dosimetry* 2015;164(3):361-7.
33. Ludlow JB, Davies-Ludlow LE, Brooks SL, Howerton WB. Dosimetry of 3 CBCT devices for oral and maxillofacial radiology: CB Mercuray, NewTom 3G and i-CAT. *Dentomaxillofacial Radiology* 2006;35:219-226.

34. Nunnally JC, Bernstein IH. *Psychometric Theory*. 3<sup>rd</sup> ed. New York: McGraw-Hill, 1994:264-265.
35. Da-Ke W, Fu-Yin S, Hong-Chen D. A high sensitivity LiF thermoluminescent dosimeter – LiF(Mg, Cu, P). *Health Physics* 1984;46(5):1063-1067.
36. Duggan L, Hood C, Warren-Forward H, Haque M, Kron T. Variations in dose response with x-ray energy of LiF: Mg, Cu, P thermoluminescent dosimeters: implications for clinical dosimetry. *Physics in Medicine and Biology* 2004;49:3831-3845.
37. Ludlow J, Ivanovic M. Comparative dosimetry of dental CBCT devices and 64-slice CT for oral and maxillofacial radiology. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology & Endodontology* 2008;106(1):930-938.